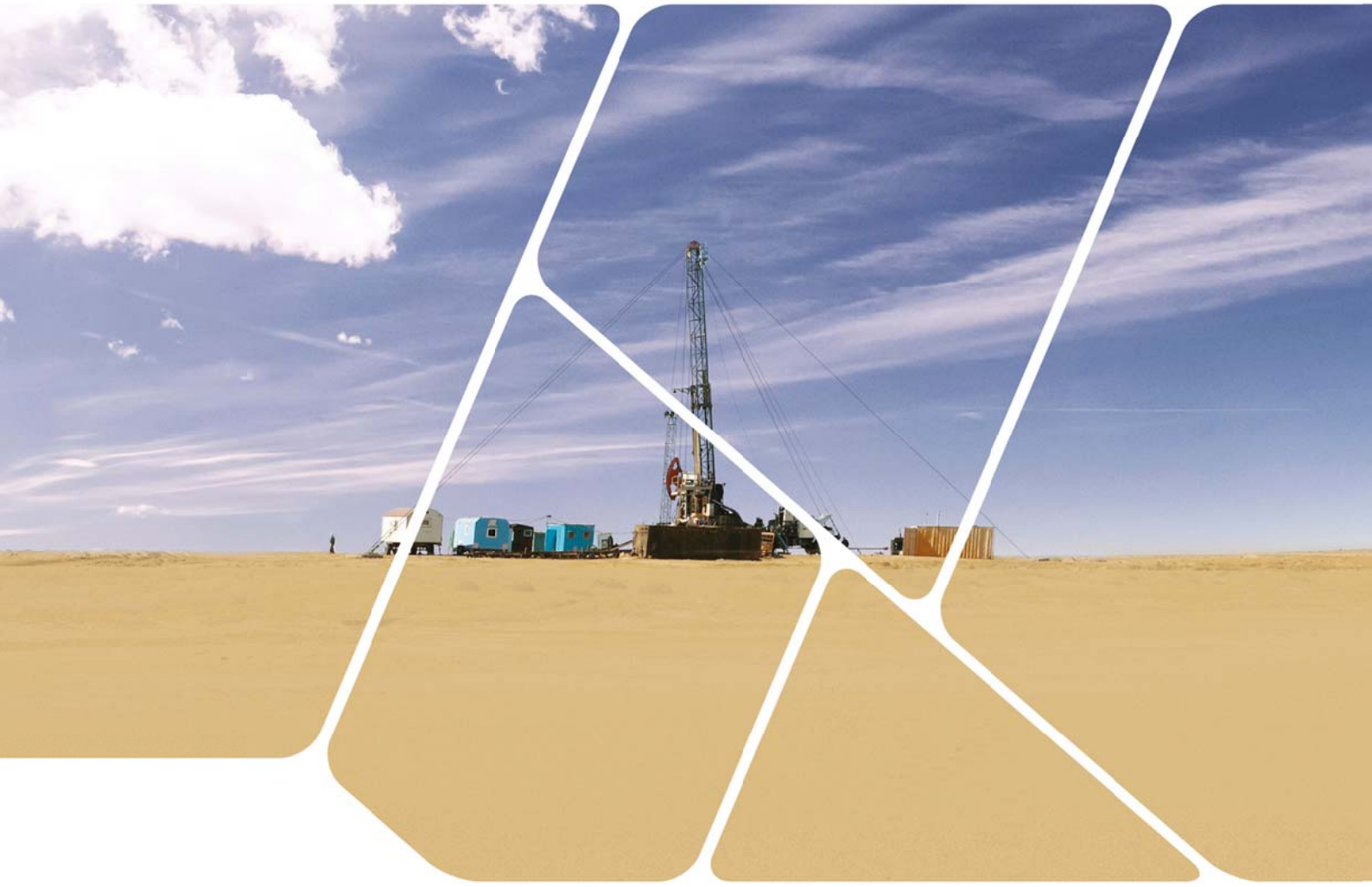


RESERVOIR ENGINEERING GRADUATE CERTIFICATE - *Week 9*

Reservoir Management

A special course by IFP Training for REPSOL ALGERIA
Alger – January 08 to 12,2017



Reservoir management & related tools

Instructor: Aissa BACHIR

IFP Training

Introduction

- What are the objectives of any *project management*?

In order to achieve we need to:

1. HSEQ
2. Reduce time of investment and increase the production life
3. Cut the cost in a reasonable way and increase the profitability

- What is *reservoir management*?

1. Let's consider a field : what kind of data do we have?
2. What volume of oil do we have? What is the expected RF?
3. What are the operating conditions?
4. Transport method any other logistic?
5. What are our ambiguities and risks?
6. How can we monitor and improve the production?

- What are RM tools?
- So the key words are:

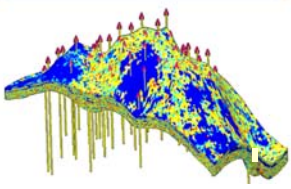
HSEQ **Reserve** **Time** **Cost** **Uncertainty and risk**

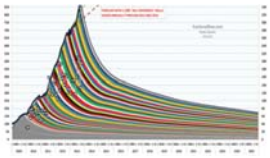
DECISION

Session program

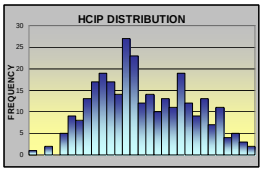
Day 1	Day 2	Day 3	Day 4	Day 5
RM Introduction Development Decision & Business Process	Economy Reservoir Characterization	Reserve Classification Profile prediction	Reservoir Monitoring	Uncertainty Assessment Final Assessment
Project	Project	Project	Project	











Objectives

- To develop an understanding of the fundamentals of Reservoir Management from Geology to Hydrocarbon Recovery and Export point,
- To promote techniques and best practices relating to the development oil & gas fields including economic aspects
- To be familiar with Petroleum Resources Management System (PRMS), Reserves and Resources definition and classifications
- To study all monitoring techniques in order to apply IOR and EOR methods during reservoir life.
- To learn about integrating risks and uncertainties into reserves evaluation – static uncertainties, dynamic uncertainties, geostochastic modeling etc.
- To provide an exposure to a range of reservoir conditions through case studies

Reservoir management and Economy

Outlines

- Introduction to Reservoir Management
- Development Decision, Business Processes & Economics
  1. Generalities, definitions
  2. Studies from Exploration to Abandonment through Appraisal, Development, Field Operations
  3. Key issues : 2G& R - RMP & RmP … other HSEQ, economics,
  4. Project Economy
  5. Cost examples

Introduction to reservoir management

Introduction: some history on petroleum technology…



- **1859-1914:**
  - Production by natural depletion
  - Imagination, empiricism, Intelligence
  - The age of drillers and wildcatters



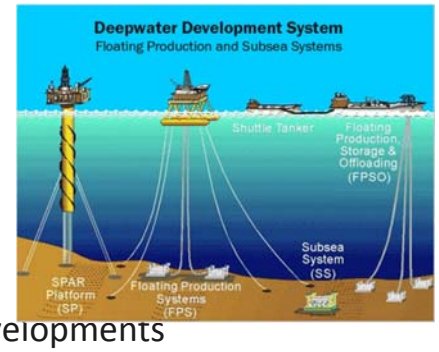
- **1914-1925:**
  - More rational production technology
  - Better well placement
  - The age of geologists
- **1925-1940:**
  - Better equipment and safety (well & surface)
  - The age of producers



Introduction: some history on petroleum technology…



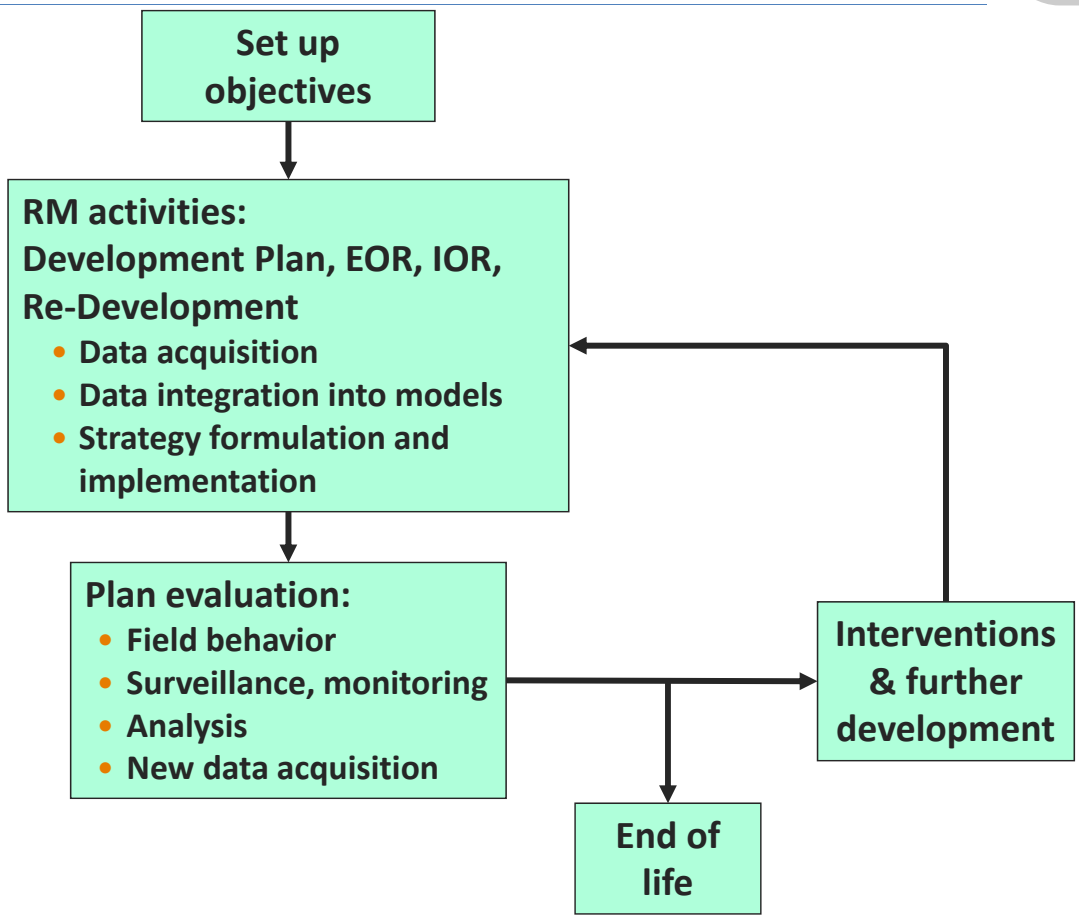
- **1940-1990:**
  - Multiphase flow in porous media
  - Optimization of recovery factor
  - Assisted and improved oil recovery
  - The age of Reservoir Engineers
- **1990…:**
  - Tough (Deep / Ultra Deep, ..) & very large scale developments
  - Asset teams - Synergies & Reservoir management
  - The age of integrated projects
- **2005…:**
  - Non Conventional (Shale Hc, tight formations) & New area developments
  - Acceptability : environment / sustainable / ethics / …
  - XXL Projects & new wildcatters ?



Reservoir management ?

- **Reservoir management is not reservoir engineering**
- **But reservoir engineering is part of it**
- **And reservoir monitoring is an important component**
- **Definition of reservoir management:**
  - It varies, depending on companies and people
  - It could be:
    - It is a strategy for applying multiple technologies and disciplines in an optimal way to achieve synergy
- **Objective of reservoir management:**
  - To reduce the uncertainty and maximize the economic value of a hydrocarbon reservoir project under the safe conditions

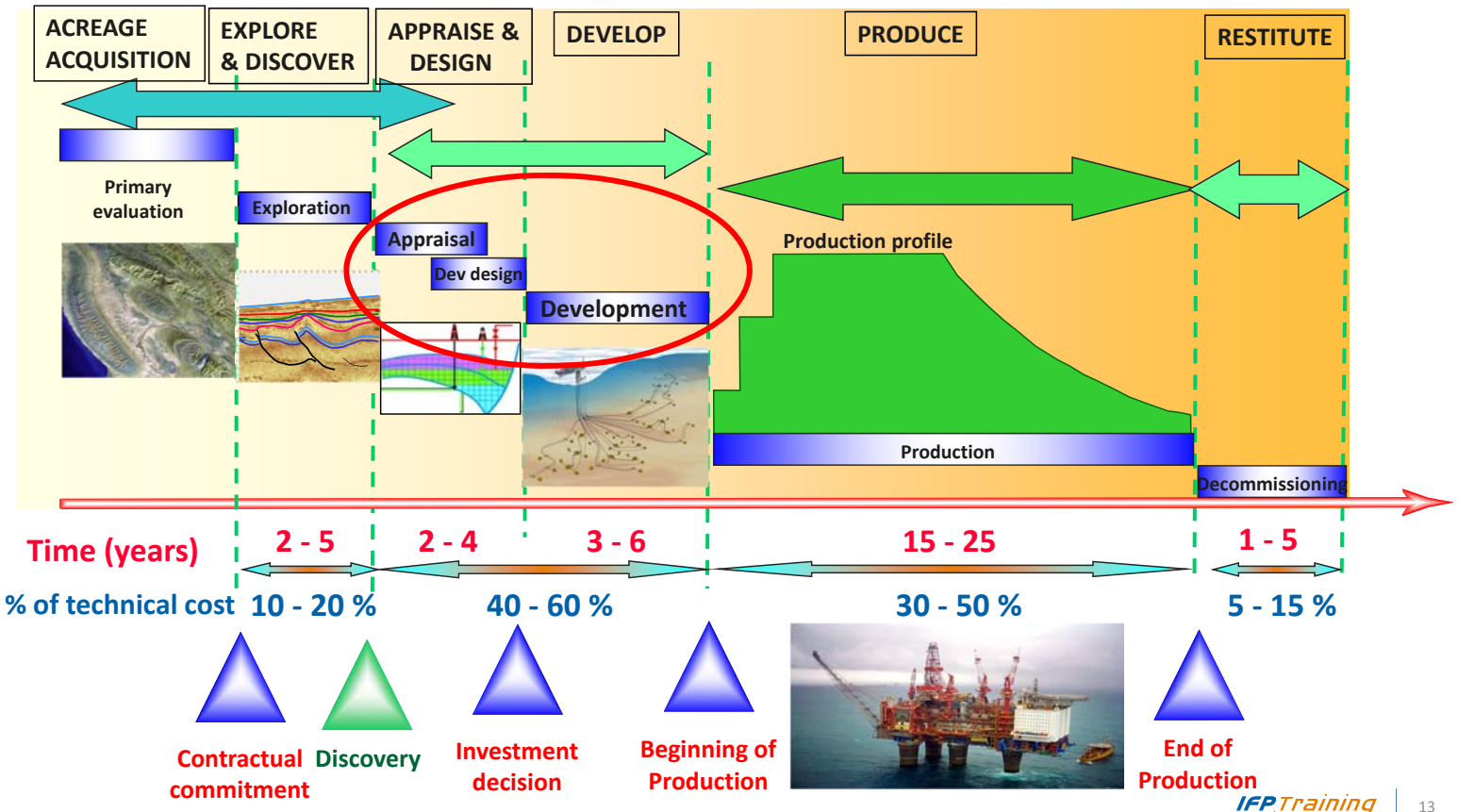
Reservoir Management Process



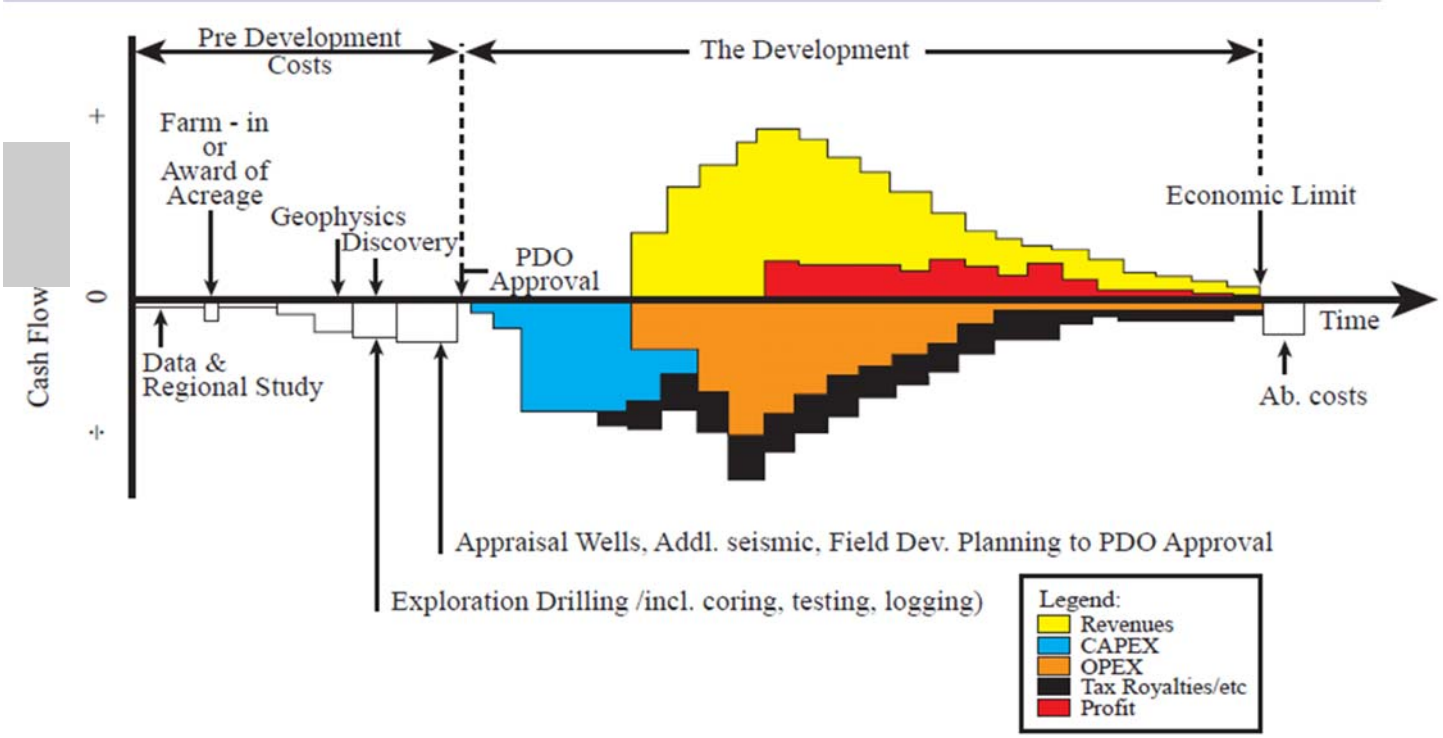
Responsibilities

- **Multi-disciplinary teams from**
  - Geology, geophysics, reservoir engineering
  - Drilling engineering, production and operation engineering
  - Research and development
  - Planning, economists
  - Environmentalists, HSEQ…
- **Each team member should be responsible for complying with the standards within his area of expertise**

Field Development Project in the E&P Operational Process



Economic Aspects



OPEX: Operational Expenditure
CAPEX: Capital Expenditure
PDO: Plan of Development and Operation

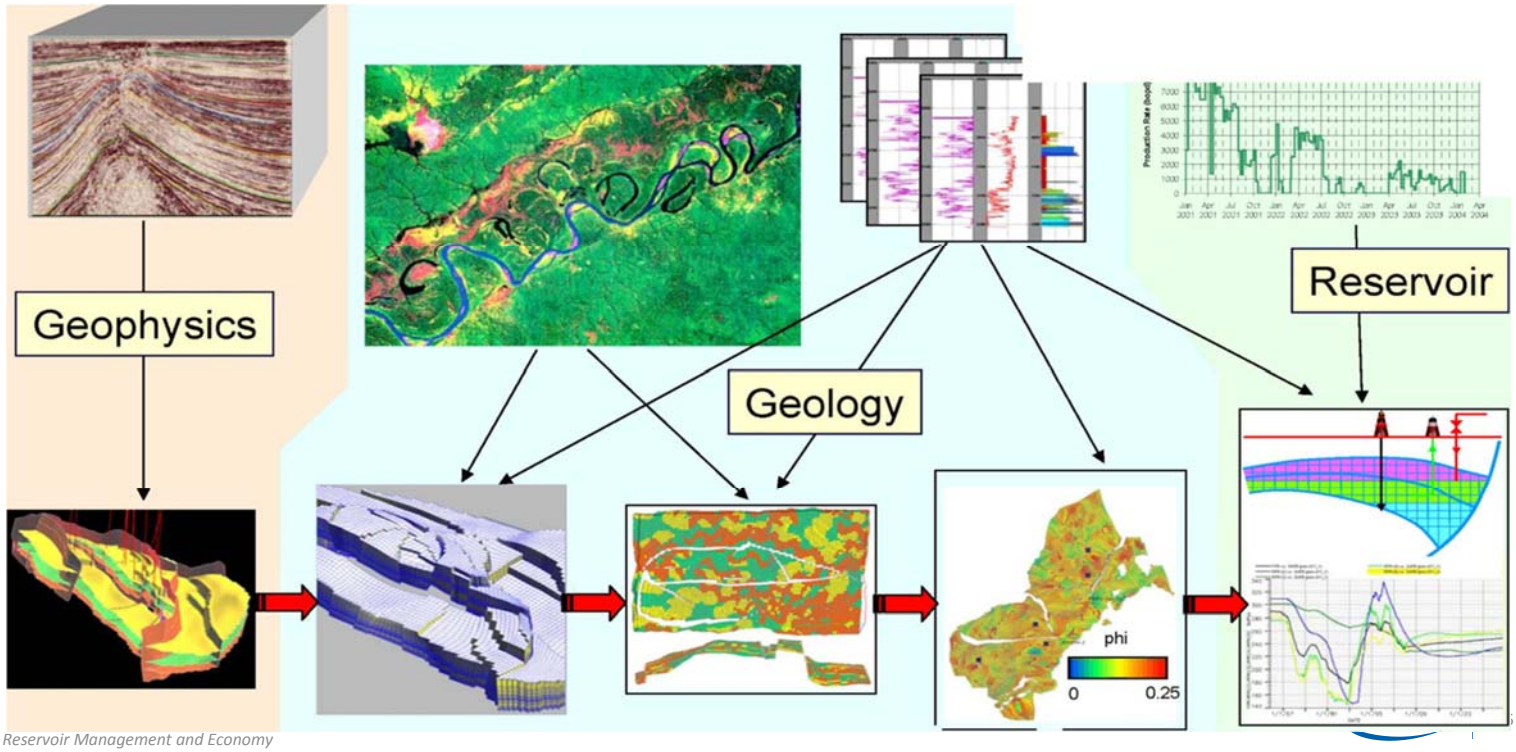
Production profiles & reserves evaluation

from simplest-analytical

$$Res = GRV*NTG*\Phi*S_o*1/B_o*RF$$

***G**ross **R**ock **V**olume* — *Φ Porosity* — ***N**et **T**o **G**ross* — ***S**aturation in **O**il* — ***Bo** Oil Volume Bottom/Surface* — ***R**ecovery **F**actor*

To the most elaborated – Integrated reservoir models

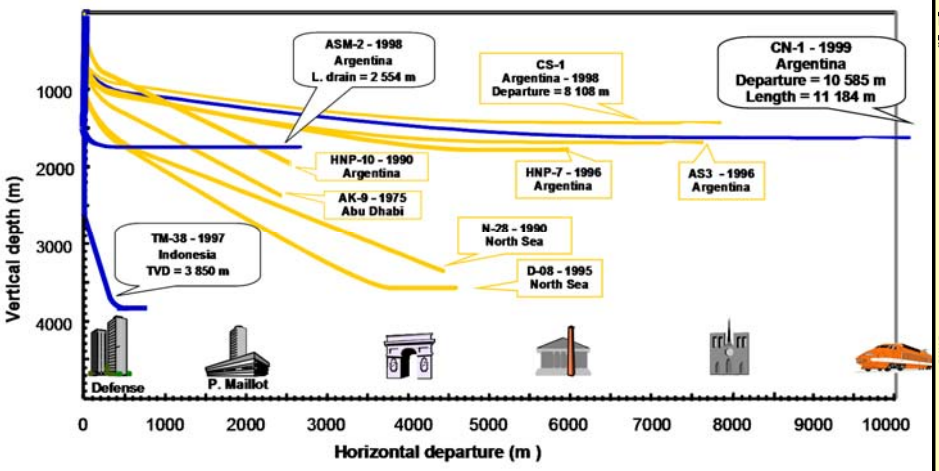


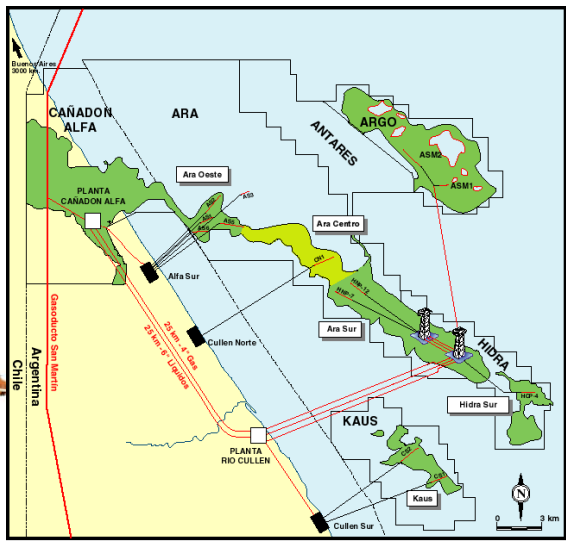
Evaluation of drainage mechanisms

- **We need to evaluate, from the beginning, what the possible drainage mechanisms could be:**
  - Natural depletion (use of own energy of petroleum system)
  - Or secondary assisted drainage (water or/and gas injection)
  - Or “more” assisted drainage (IOR/EOR, ..)
- **However, assisted drainage is seldom implemented right from the beginning (at least in poorly known area/region)**
- **It is preferable to start producing the field by natural depletion, even for a very short period,**
  - In order to monitor and observe the field behavior
  - And decide on the nature of the drainage mechanism from the dynamic data
- **Uncertainties will remain and should be managed all along fields life**

Drainage mechanisms with well drilling & completions

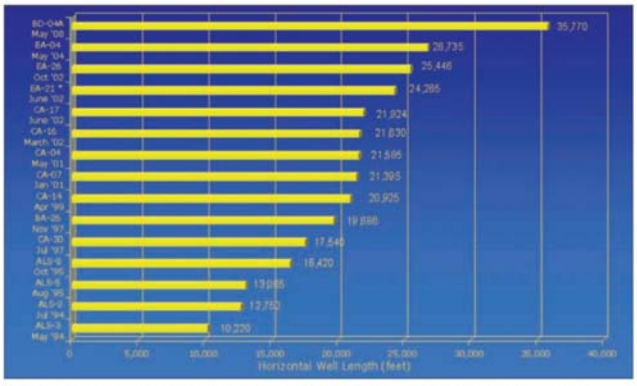
- Well engineering has evolved tremendously and may have a great impact on flow insurance and improved oil recovery
- A good example would be the extended reach wells in Tierra del Fuego (Argentina) to tap oil reserves that otherwise could not be economically produced





Al Shahin field well pattern





This graph shows record wells by Maersk Oil Qatar. In 1994, 10,220 ft was the longest horizontal length drilled by MOQ.

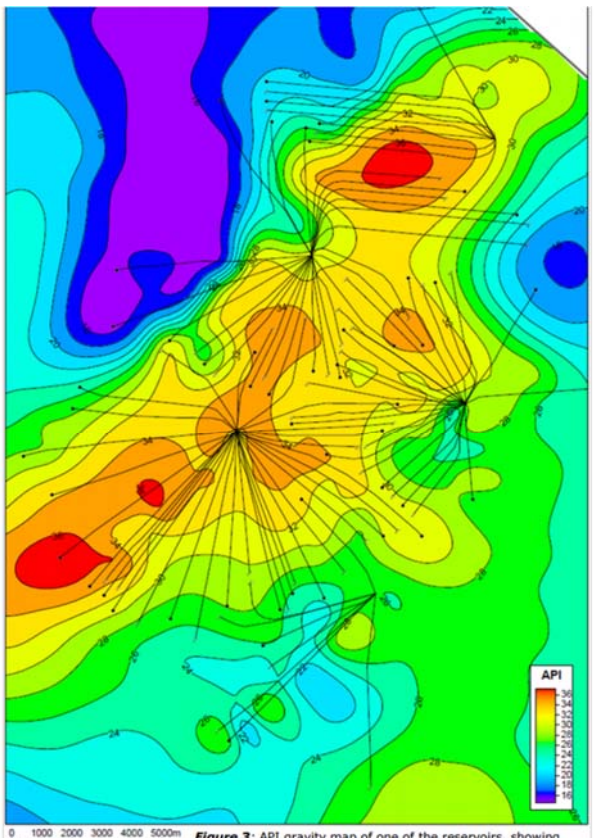


Figure 3: API gravity map of one of the reservoirs, showing location of horizontal development wells *(Lindeloff, 2008).*

Well drilling and completions

- **Another good example of the complexity of drilling is given in a field case in Colombia:**
  - the most advanced techniques were used to drill in a tectonically complex environment (in-situ stress field, variations in rock resistance and pore pressure)
  - Problems of stability or fracturation by invasion, well collapse, cementation problems
  - 20 to 30 million US$ per well,
    more than 100 wells



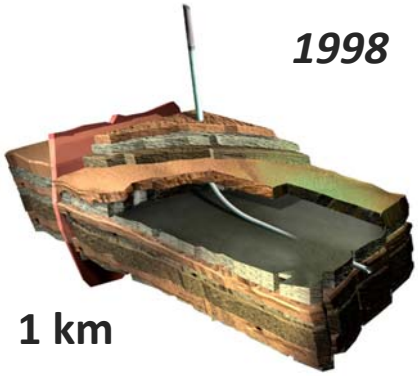
Horizontal drilling

Observation

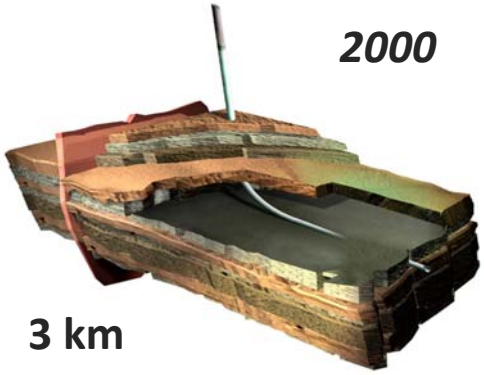
- **Principle: watching a video about horizontal drilling**
- **Object of the game: to see how important the different technologies and the tools are in reservoir management and development**
- **Timing: 5'**



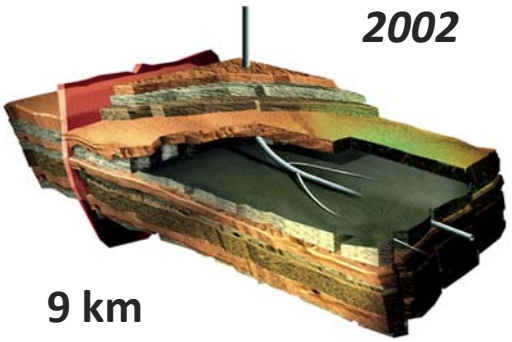
Evolution of horizontal drilling



Horizontal



Horizontal



MRC (Multi-lateral)

Maximum Reservoir Contact (MRC)

- A well with an aggregate reservoir contact in excess of 5 kilometers via a single or multi-lateral configuration



Location of the Shaybah oil field within Saudi Arabia

E&P specificity: a high technology content

A few examples all over the world



UK : Elgin Franklin

High Pressure 1100 bars

High temperature 200° C

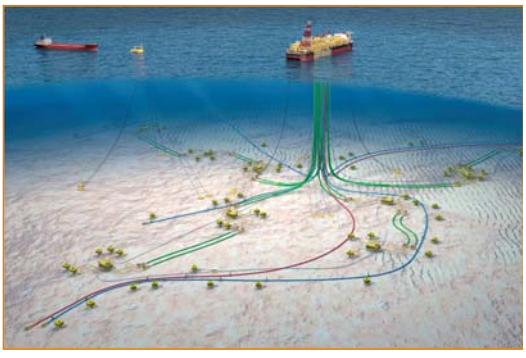
Well depth 5300m



Venezuela : Petrocedeño

Extra heavy oil

Upgrading facilities



Angola : Girassol

Deep offshore (1400 m water depth)

Uncertainties in reservoir characterization

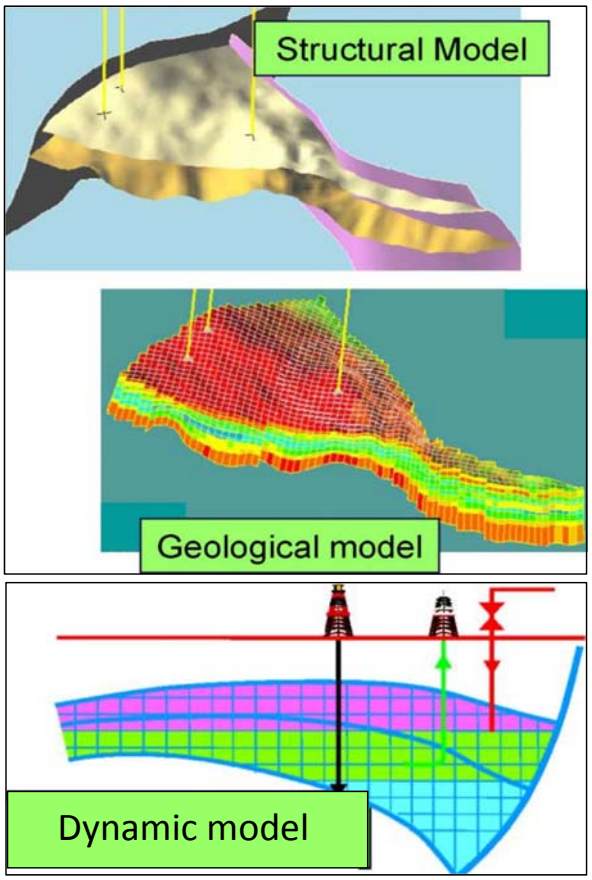
- **A great number of uncertainties can be identified in this process. These can be grouped into three main categories:**
  - Geophysical uncertainties that affect the reservoir envelope
  - Geological, sedimentary and petrophysical uncertainties that impact on the content of envelope and the HC volume in-place
  - Dynamic uncertainties that impact on the reserves and production profiles
- **For each case, all the potential uncertainties**
  - Must be identified
  - And assessed in terms of their impact
  - And then ranked so that only major uncertainties will be kept and integrated into the whole process

Uncertainties in reservoir characterization

GEOPHYSICS	GEOLOGY	DYNAMICS
Migration	Geological and Sedimentary concept	Fault Transmissivities
Velocity law	Extension and Orientation of Sedimentary Bodies	Extension of Barriers
Picking	Distribution, Shape, Limits of AE / RT	K model
Time-depth	Populating the model : k, phi, NTG, Sw...	Kv/Kh
Seismic-to-well tie	Contacts	Viscosity, PVT
Faults Location	...	Kr Shapes and End Points
		Aquifers
		Rock Compressibility
		Well PI, II
		...

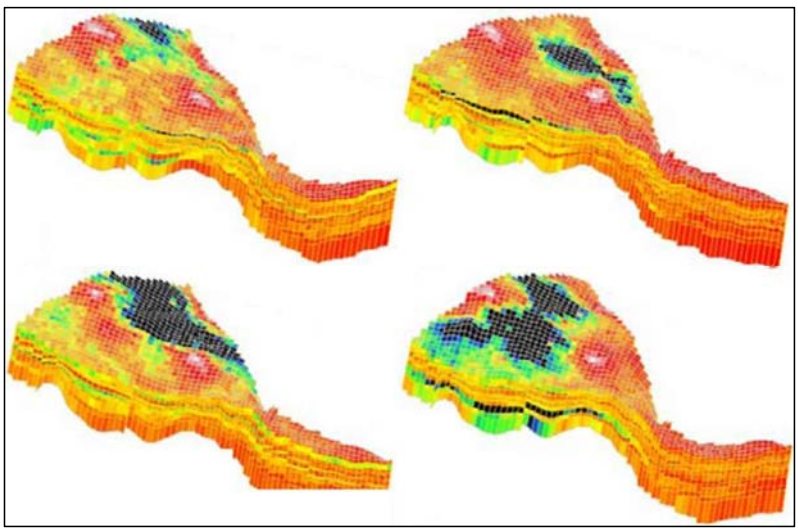
Objectives & management of 2G&R uncertainties

- **Objective: To determine optimal development plan and associated 1P to 3P reserves**
  - Taking all the uncertainties into account
    - Structural
    - Petrophysical
    - Dynamic
  - With or without history match
- **Uncertainties assessment is necessary:**
  - To make good decisions
- **Means: reservoir model**
  - Incorporating all the subsurface data
  - From geophysics to geology to dynamics
  - History match if necessary

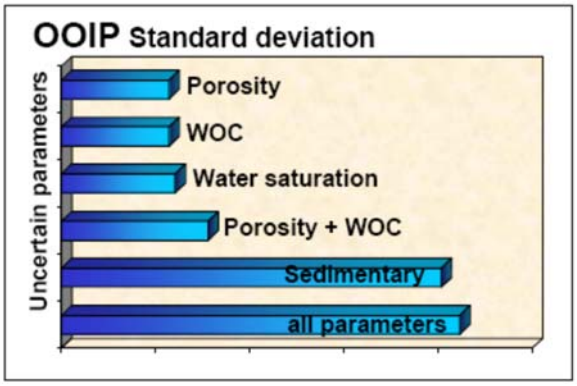


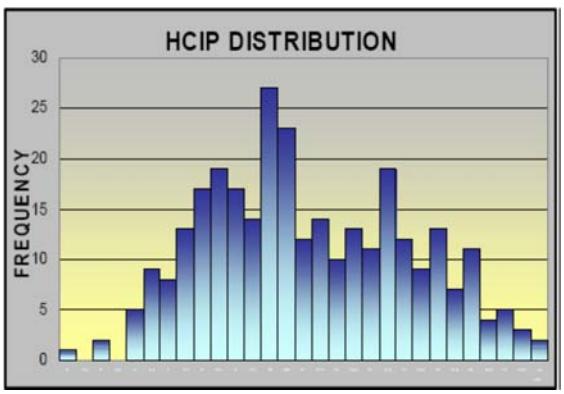
HIIP probabilistic distribution – G&G

- **Results of the geological and structural uncertainties**
  - Distribution of hydrocarbons in place
  - Ranking of the uncertainties
  - Reservoir models



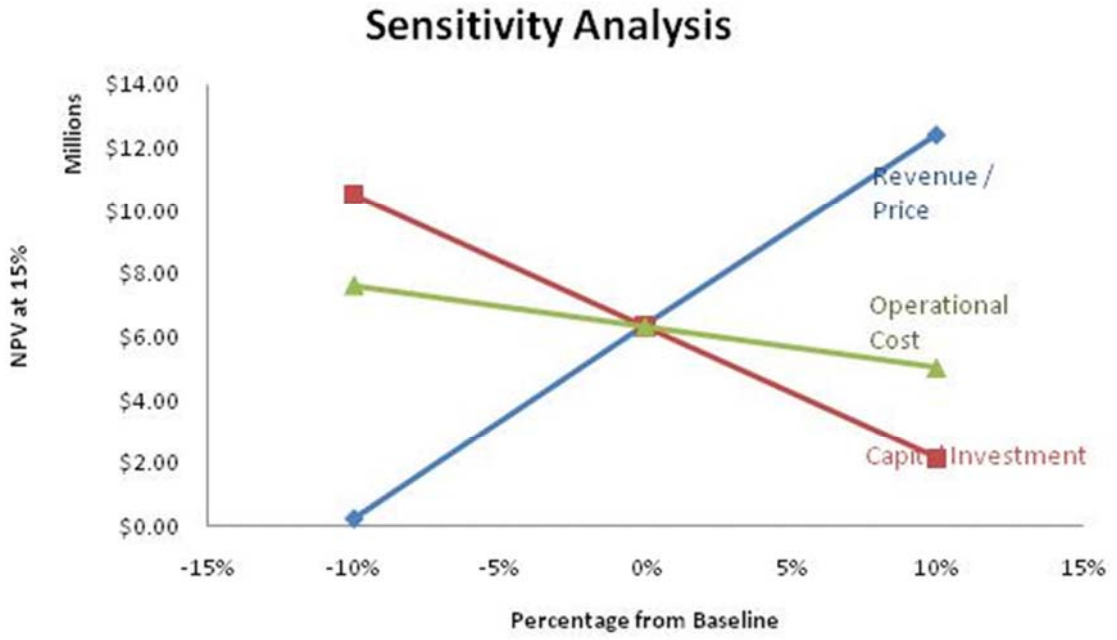
Hz permeability





Uncertainty in economy

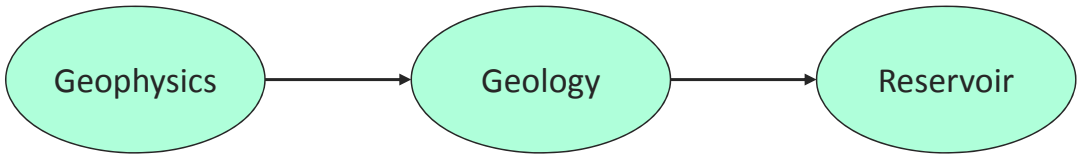
- **Your profitability (NPV, IRR) is sensitive to CAPEX, OPEX and hydrocarbon price.**



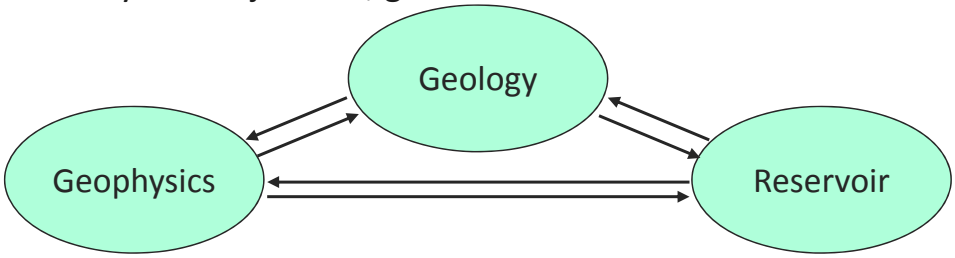
Reservoir management plan

2G&R and reservoir management

- **Reservoir management requires an integrated multi-disciplinary team**
- **Before RM: sequential approach**
  - Different hierarchies and objectives, poor communication



- **After RM:**
  - Common hierarchy and objectives, good communication



Reservoir management plan

- **The RMP is a "Road Map" for the Asset team summarizing the current development information and strategy**
- **It is a synthetic (... but not short) document:**
- **Dealing with all the main aspects for geosciences**
  - In particular reservoir engineering
  - But providing data on the contribution of other domains (drilling, economics, field operations, ..)
- **Associated to the field development plan(s)**
- **Generally addressed in the pre-project phase**
- **It pinpoints:**
  - The project objectives
  - The project status and remaining uncertainties & risks (potential impact included upsides)
  - The future actions and planning (data acquisition, field management, monitoring plan, …)
- **It should be approved by Management at headquarters and be used as a "law enforcement" document within the subsidiary**

Reservoir management plan: overall content

- **Executive summary**
- **History / status of the project**
  - History wells, exploration / appraisal / exploitation,
  - Overall context & constraints (technical, legal, environmental, …)
- **Development & strategy**
  - Objective,
  - Production mechanism, facilities, wells,
  - 2G&R details Profiles / reserves, …
  - Global risks / uncertainties, planning / uncertainties, costs, …
- **Reservoir management**
  - Reduction of uncertainties during development, sequences, well preparation, …
  - Opportunities proximity appraisal, mitigation plan, upsides identification, …
  - Monitoring plan / strategy, studies to complete, …
  - Human resources, ..

In summary … FDP: a multi-disciplinary team



- **Objective of Reservoir Management:**
  - To maximize the economic value of a hydrocarbon reservoir under the safe conditions
- **This means managing of time and money and considering all uncertainties.**
  - The RMP is a “Road Map” for the Asset team summarizing the current development information and strategy
- **Responsible for Multi-disciplinary teams from discovery to abandonment**



Development decision, business processes & economics

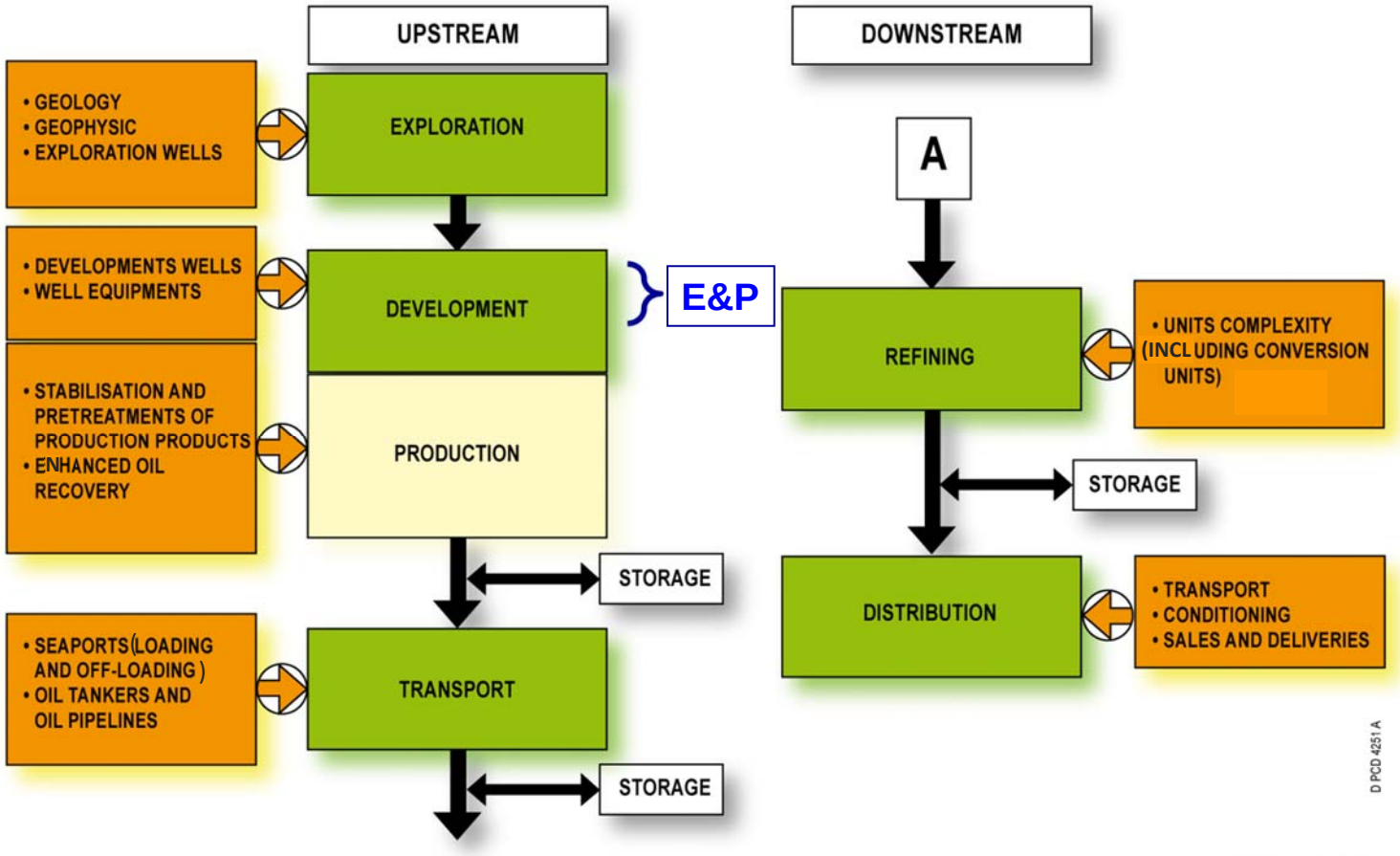
Outlines

1) **Generalities, definitions**
2) **Studies from exploration to abandonment**
3) **Key issues**
   - 2G&R issues– RMP & RmP
   - Many other issues – HSEQ & Economics
4) **Project economy**
5) **Cost examples**

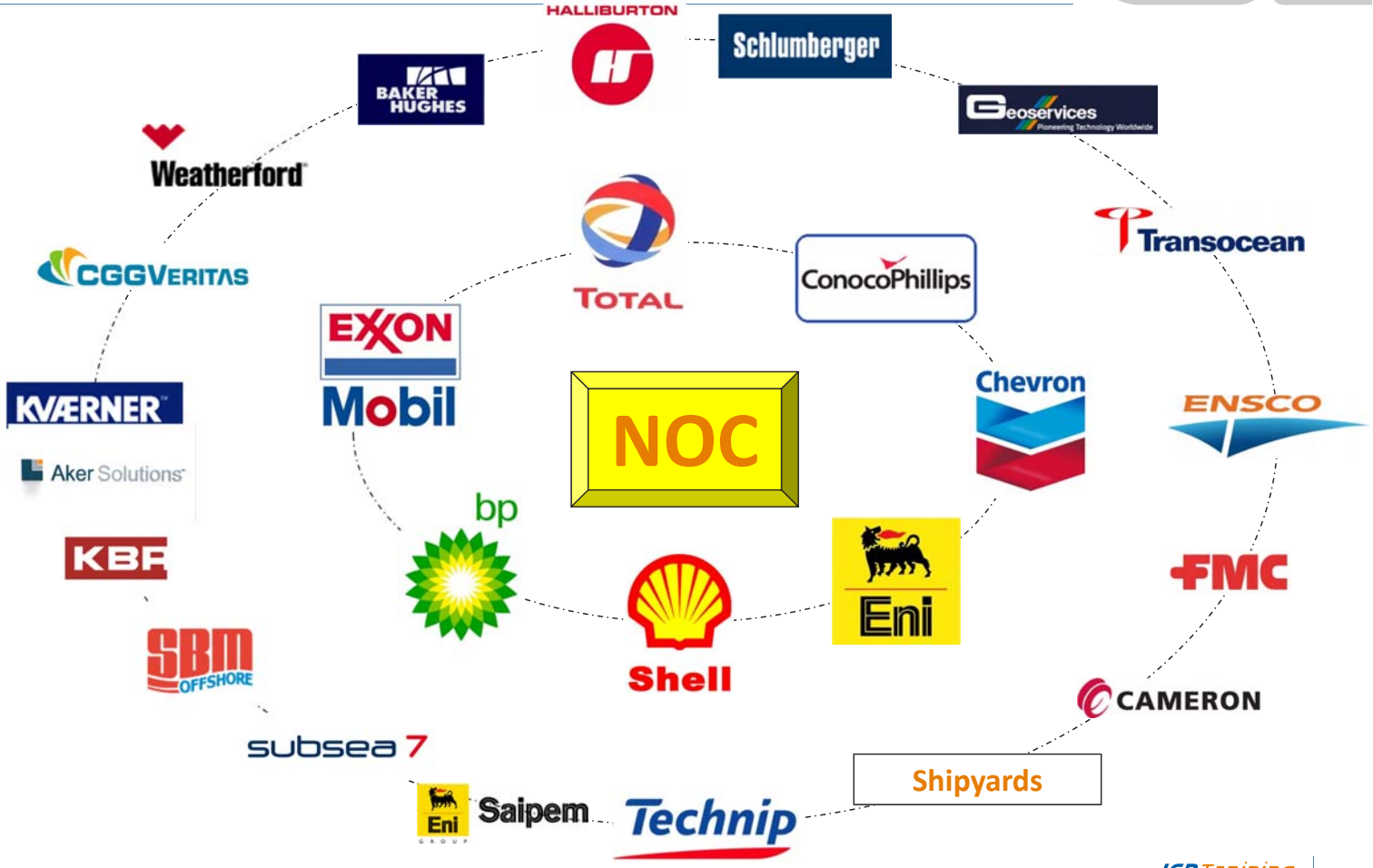
Development decision, business processes & economics

- 1. Generalities, definitions

Generalities in E&P Oil and Gas activities chain



E&P: Main actors (NOC, IOC, services companies)



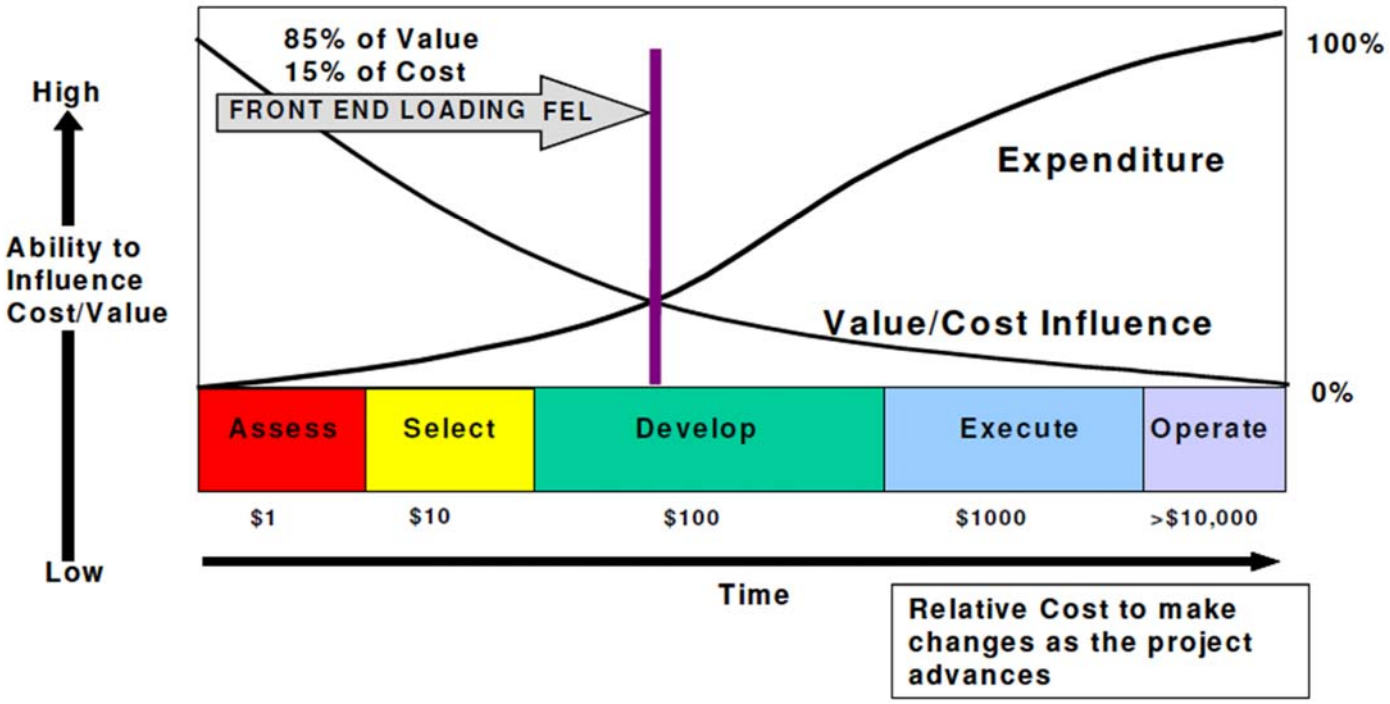
How does the process works?

SUMMARY OF OPREP PROCESS

	PHASE 1 ASSESS	PHASE 2 SELECT	PHASE 3 DEVELOP	PHASE 4 EXECUTE	PHASE 5 OPER&EVAL
OBJECTIVE	Determine potential value of the opportunity & alignment with the business strategy	Generate and select the preferred opportunity alternative	Finalise scope, cost, schedule and get project funded	Produce an operating asset consistent with scope, cost and schedule	Start-up, operate, evaluate asset to ensure performance specifications & maximum return to shareholders
KEY DELIVERABLES	Valuation Report	Development Plan	Business Proposal Package	Functional Assets	Performance Assessment
KEY DECISIONS		Approve Feasibility Study	Approve Development Plan	FID Approval	Operations Acceptance / Value Enhance
KEY ASSURANCE CHECKS	AC1 • Project Initiation Review	AC2 • Feasibility Review • Development Plan (Concept Selection) Review	AC3 • Final Investment Decision Review	AC4 • Pre Start Review	AC5 / AC6 • Post Investment Review

OPREP (Opportunity and Project Realization Process) **(from D. Dow, Woodside)**

Cost of change!

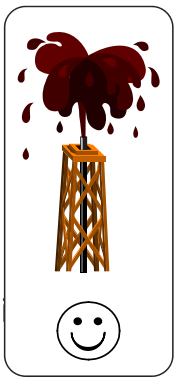


(from D. Dow, Woodside)

All companies have their own processes with different terminologies

Company	Stage-gate variant				
	Gates	Feasibility	Concept selection	Sanction	Ready for start-up
bp	•Appraise	•Select	•Define	•Execute	•Operate
EXXON Mobil	•Feasibility	•Evaluation and selection	•FEED & Detailed design	•Construction	•Operation
Chevron	•Identify and select alternatives	•Generate and select alternatives	•Develop alternatives	•Execute	•Operate and evaluate
Shell	•Identify and assess	•Select	•Define	•Execute	•Operate

Definitions (1/2)



Exploration

- Mainly involves seismic data acquisition and exploration wells
- Statistically, only 1 to 3 wells out of 10 are successful
- The exploration phase ends once a discovery has been made
- After a discovery, preliminary studies are performed to evaluate its commercial

Appraisal & conceptual

- Once hydrocarbons have been discovered and preliminary studies draw positive conclusions, appraisal works and further studies are often necessary before the decision to develop can be made:
  - To reduce the uncertainties
  - To evaluate different scenario of development till selection of a concept
  - To provide sufficient data for the development studies
  - Mainly involves drilling delineation wells and associated works & studies

Definitions (2/2)

Development / Construction

- Includes all the activities that follow the exploration and appraisal phases until production start up.
- It covers mainly:
  - Development studies
  - The preparation for the decision to develop
  - Engineering, fabrication and installation of the facilities
  - The tests before production start-up

Production

- Includes all the activities to ensure safe and reliable oil/gas production
- It covers mainly:
  - The start up of the production facilities & product delivery
  - The operation, control and monitoring of the facilities
  - Inspection, workovers, maintenance and repairs
  - Commercial, fiscal metering and reporting

Field/plant abandonment

- Conditions to dismantle a plant, abandon wells and restore a site



Development decision, business processes & economics

- 2. Studies from exploration to abandonment through appraisal, development, field operations

Field evaluation process

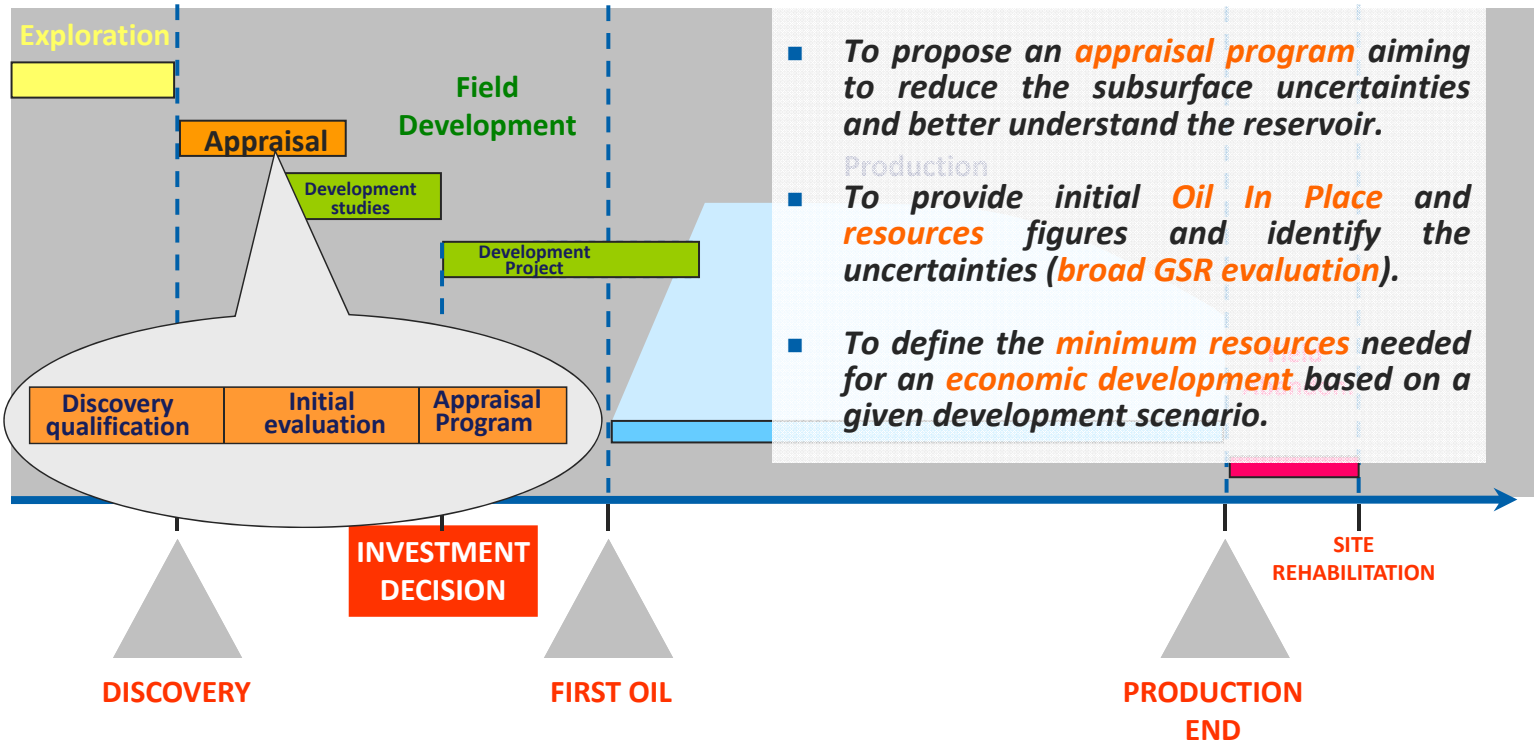
- **After an oil or gas discovery has been made, there are several key questions to answer:**
  - What to do with this discovery? Opportunity to develop it, or not?
  - How much oil/gas can be produced? (profiles, reserves)
  - Which development scheme to select? (mechanisms, facilities)
  - How much will it cost? (Capex, Opex, contracts)
  - How long before production start-up? (planning, studies, FID, …)
- **Development studies are performed to answer these questions**
- **If answers are encouraging, then the decision to go ahead with the project may be taken**

Field evaluation process

- **Objectives of the field evaluation process:**
  - To define the development scheme allowing the optimization of the hydrocarbon recovery at the lowest cost, taking the reservoir (and others) uncertainties into account

- **The 3 phases of the field evaluation process**
  - Initial evaluation and preliminary studies
  - Conceptual studies
  - Pre-project studies

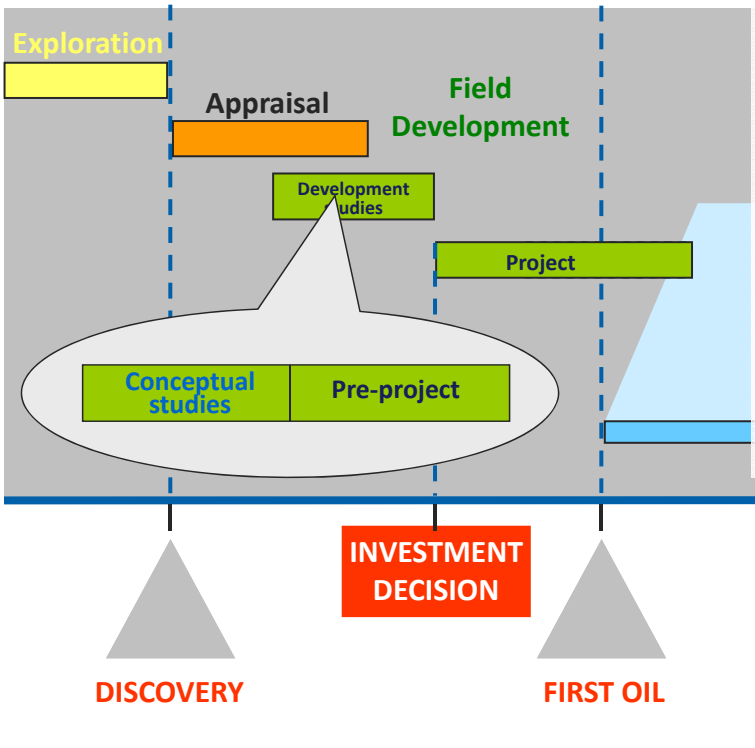
Appraisal phase



Objectives:

- ***To propose an appraisal program aiming to reduce the subsurface uncertainties and better understand the reservoir.***
- ***To provide initial Oil In Place and resources figures and identify the uncertainties (broad GSR evaluation).***
- ***To define the minimum resources needed for an economic development based on a given development scenario.***

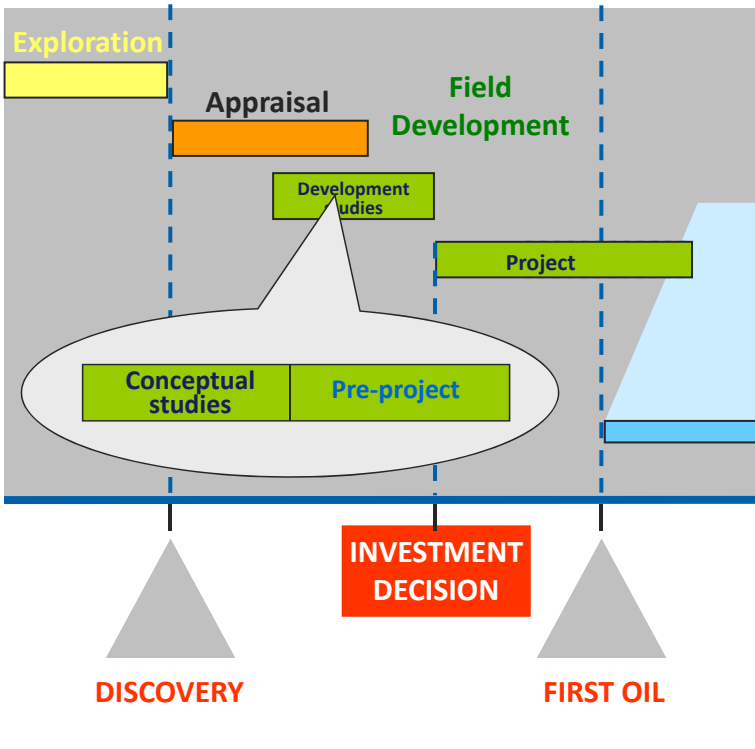
Development studies phase



Objectives: Conceptual studies

- *To compare several development scenarii and recommend the best one (Concept selection)*
- *To identify the GSR remaining reservoir uncertainties and propose a program to reduce them (complementary appraisal or specific data acquisition during development)*
- *To confirm the economy of the project based on the recommended scenario*
- *Evaluate cost & duration of pre-project phase*

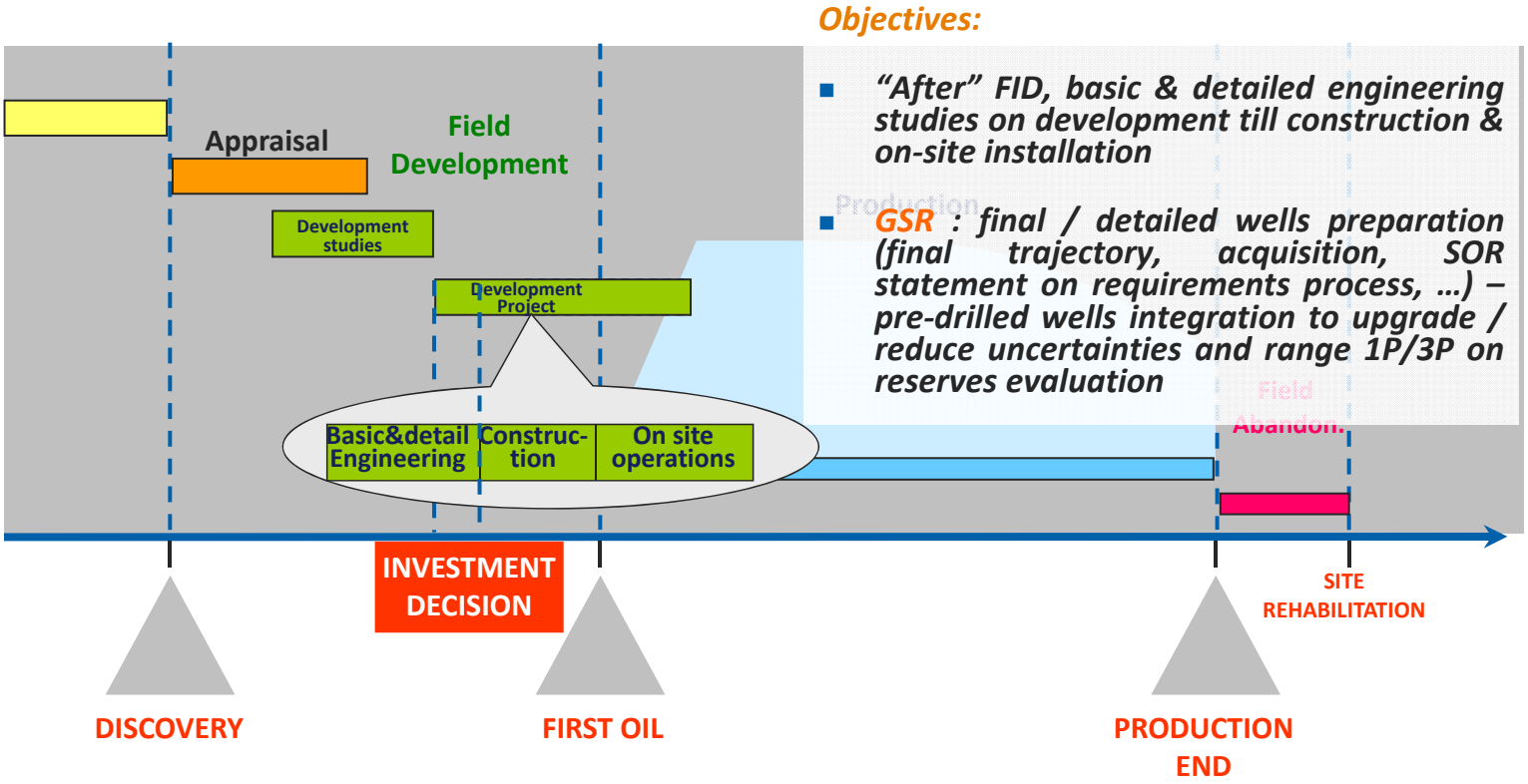
Development studies phase



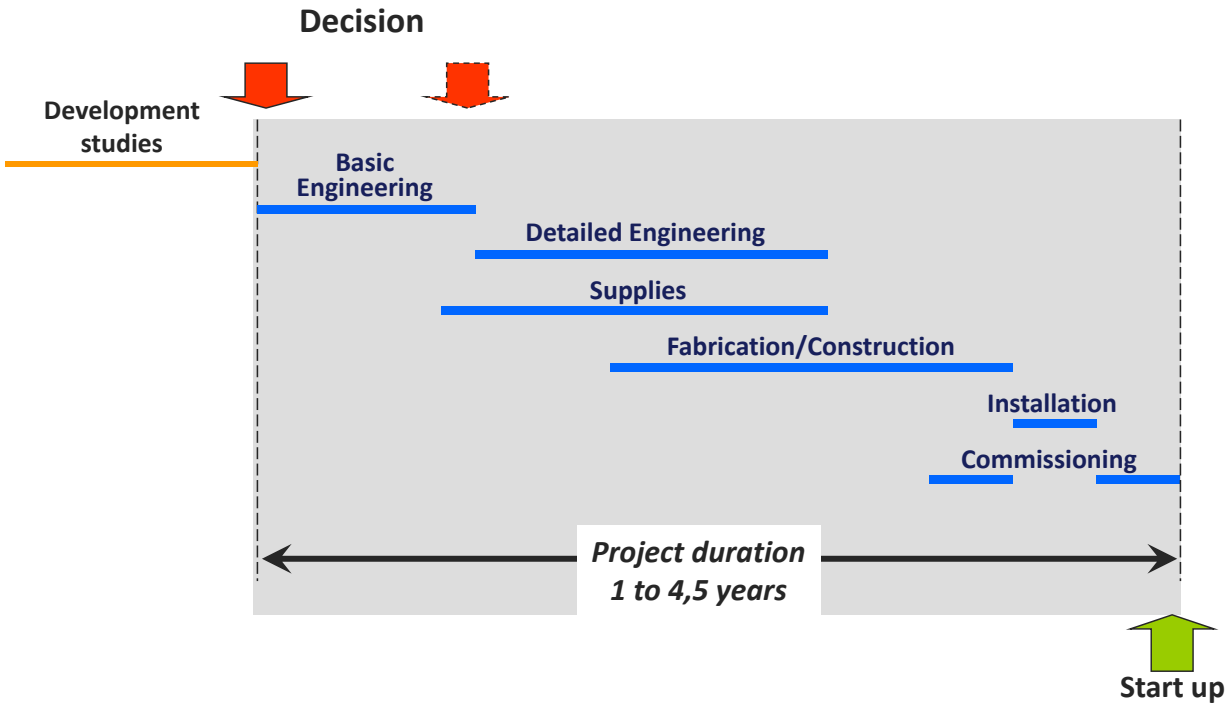
Objectives: pre-project studies

- *Once one concept/scenario has been selected, refined works and studies for additional / marginal cost savings opportunities*
- *Detailed reservoir studies – RMP issuing*
- *To validate the economy of the project based on the recommended scenario*
- *To provide elements necessary for the final investment decision (Project)*

Project/Construction phase

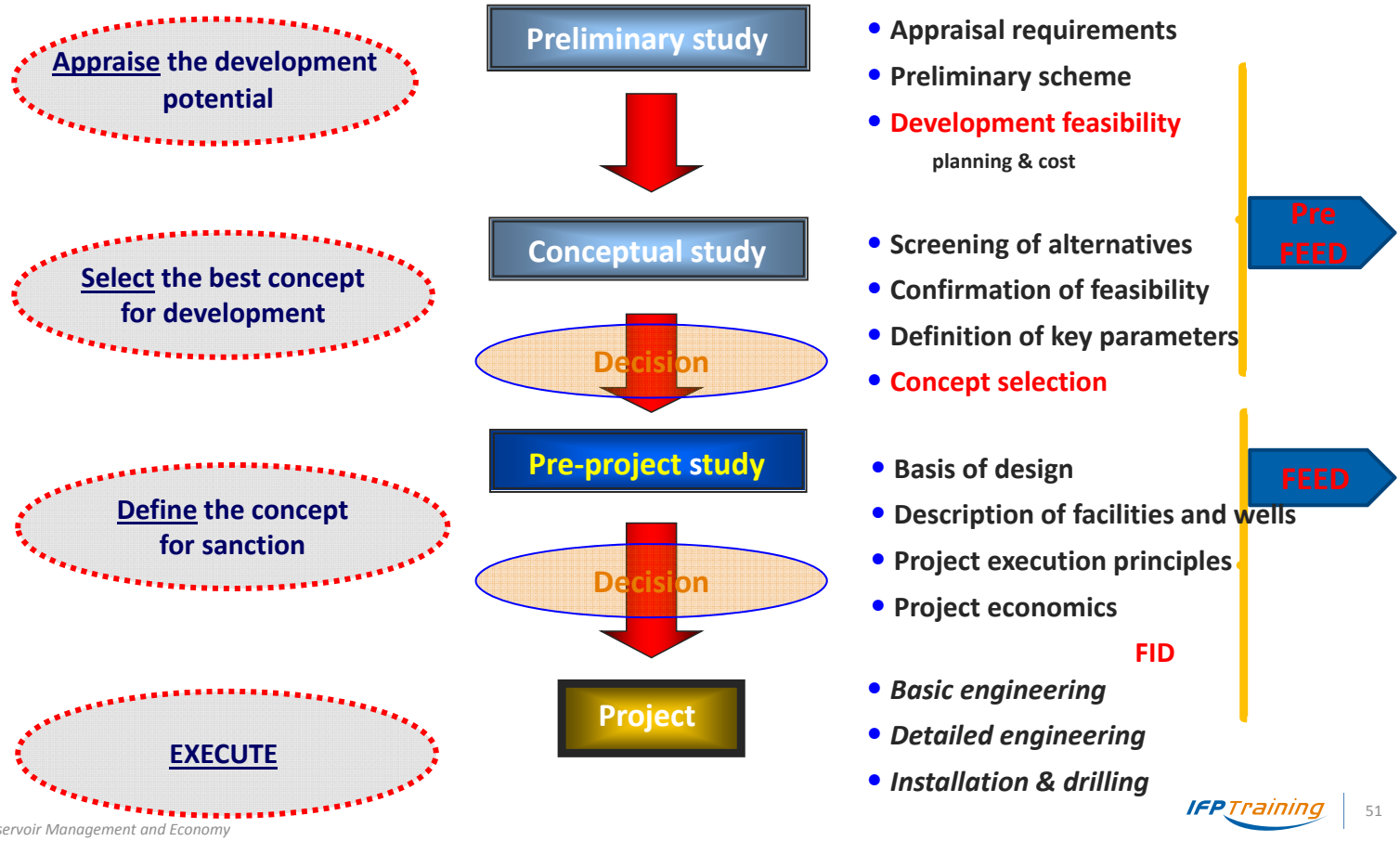


More details in the project phases

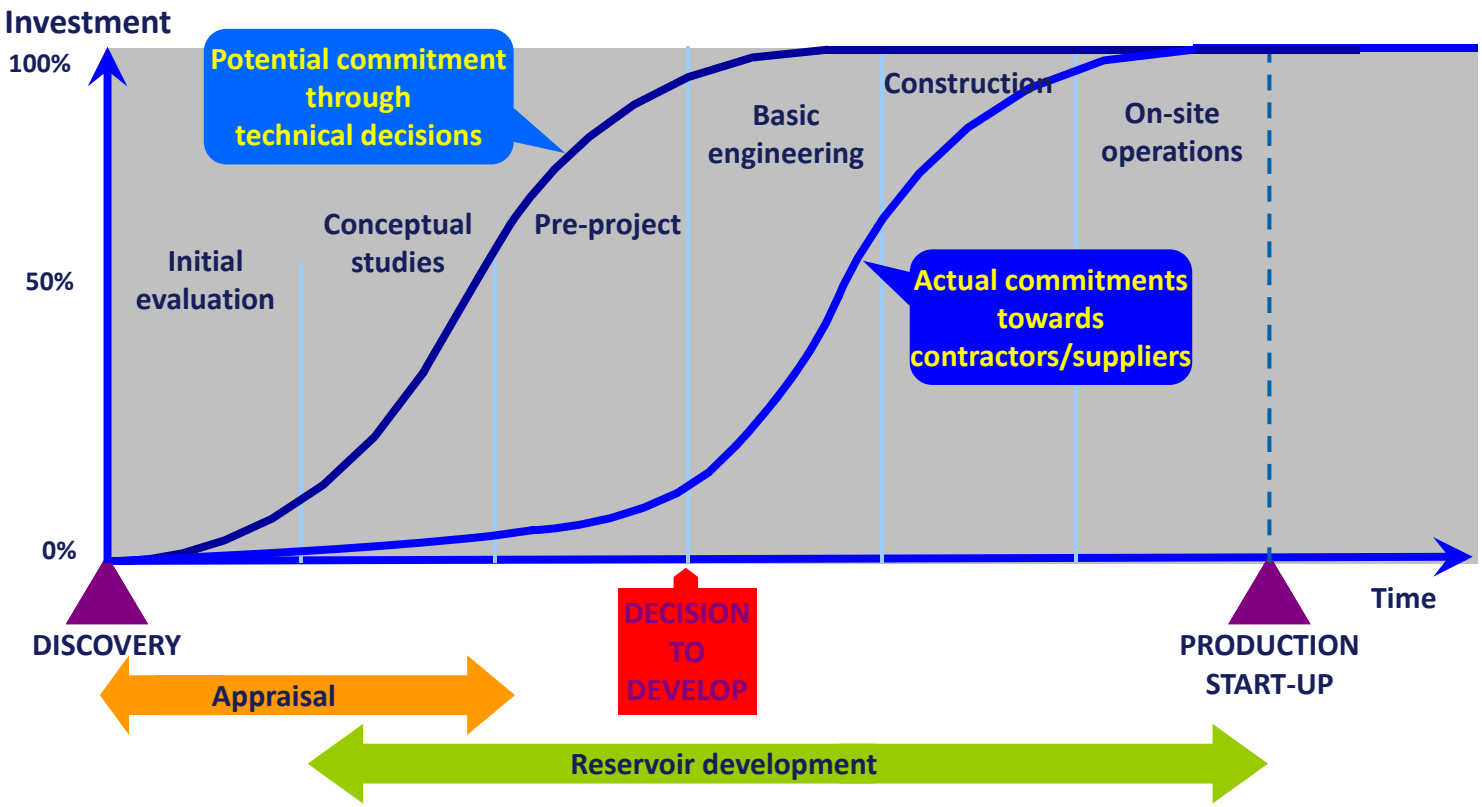


***Basic Engineering**: aims to narrow and refine the technical definition of the project and to prepare the calls for tender for the main purchase orders and contracts*

Development studies: objectives & key activities

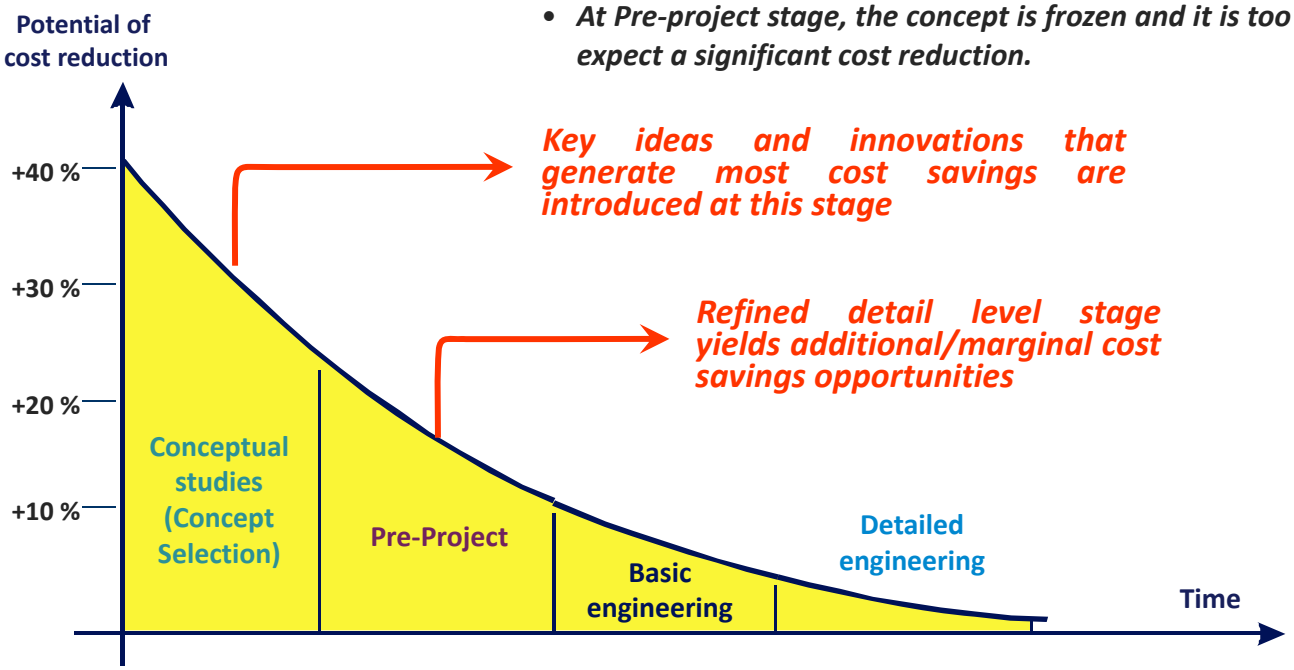


Development process and CAPEX commitments



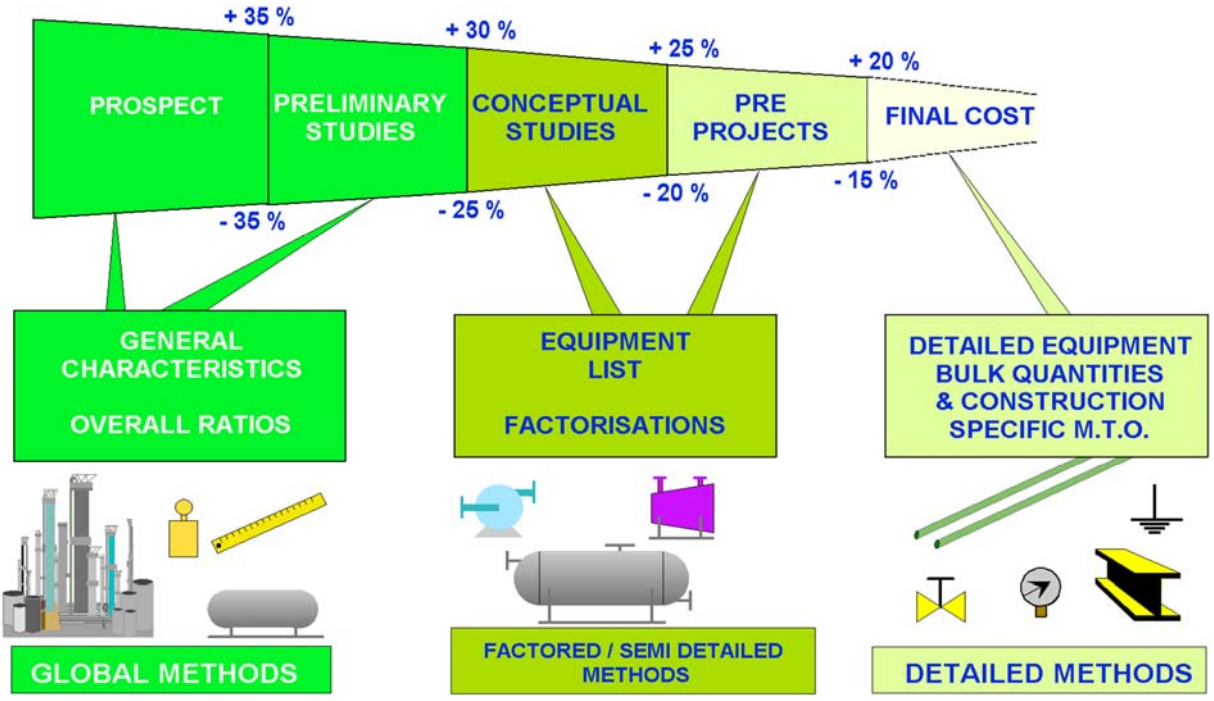
Impact of early studies on development costs

- *It is at concept selection stage that the ideas that can decrease costs have to be generated.*
- *At Pre-project stage, the concept is frozen and it is too late to expect a significant cost reduction.*



Potential cost reductions should be identified early

Cost estimation methodology



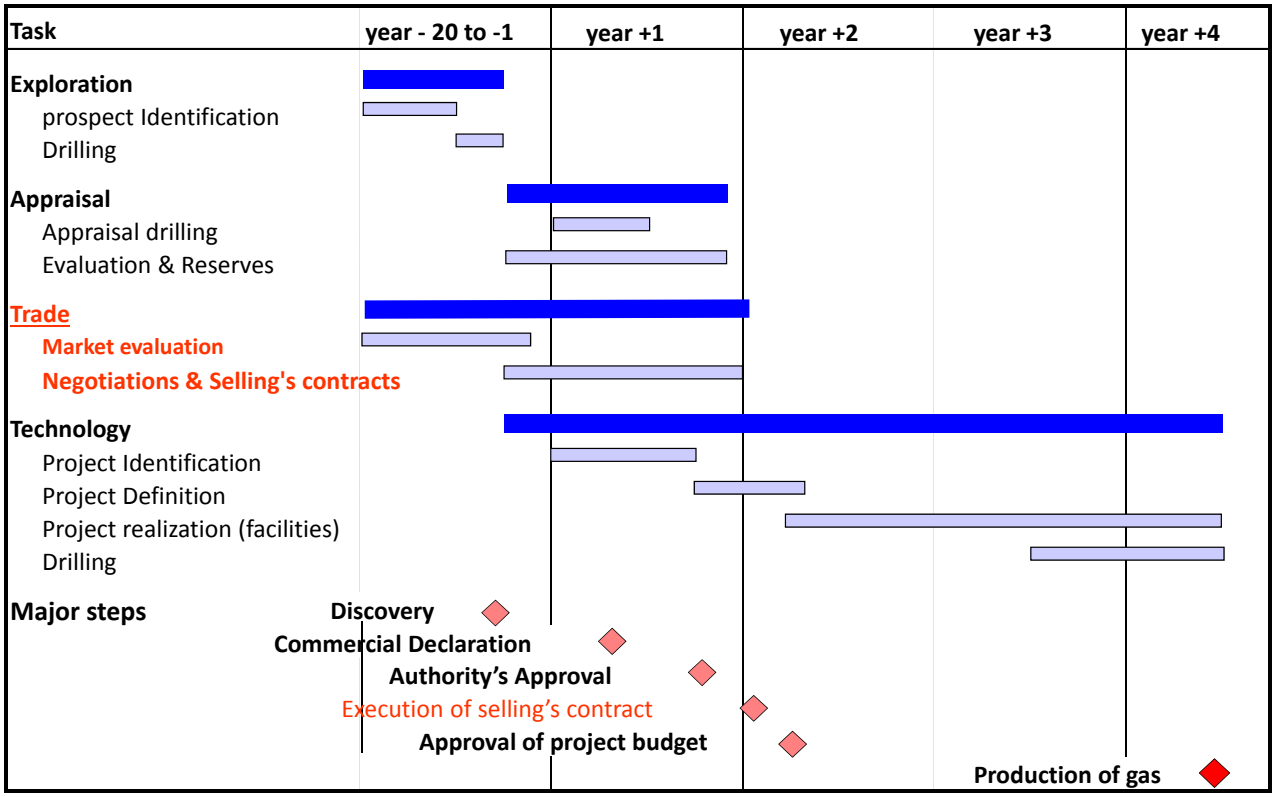
Gas and oil filed development

Debate

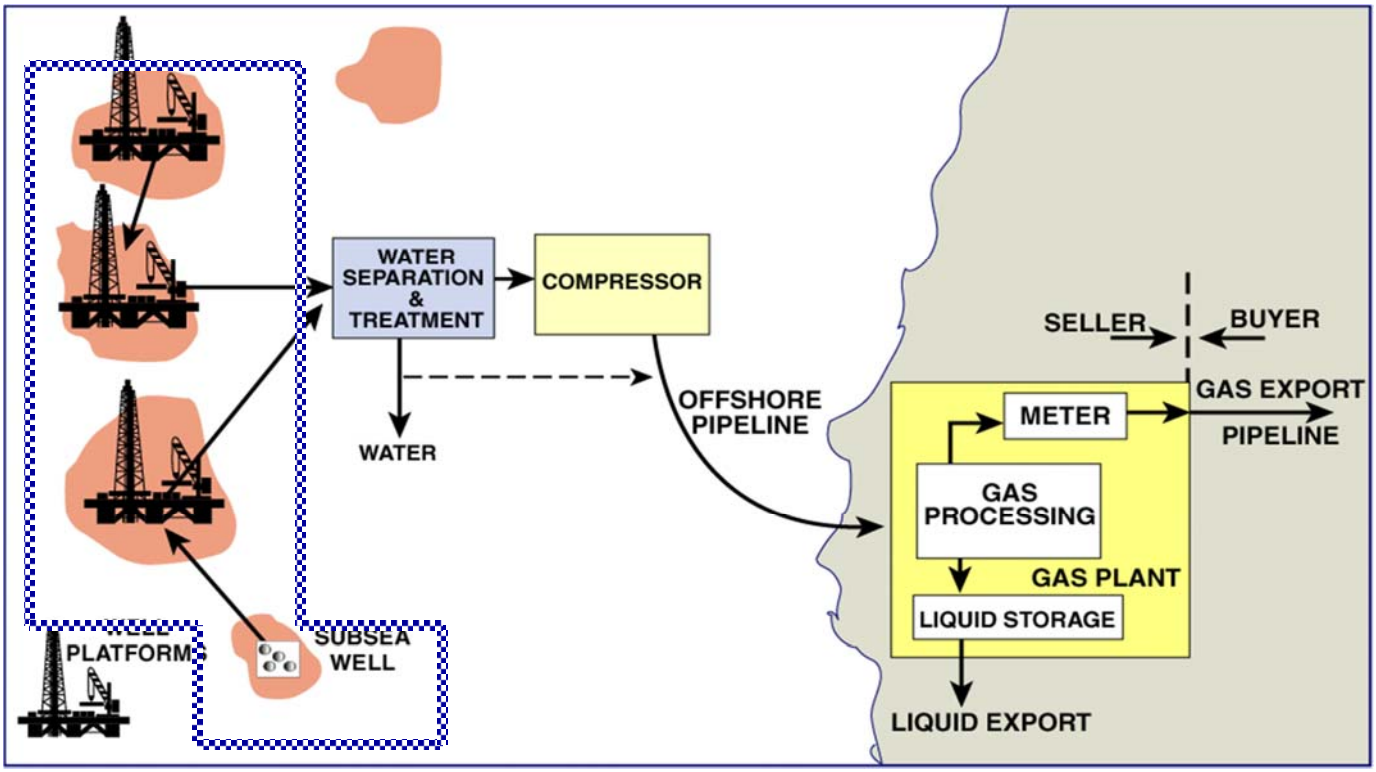
- **Principle: debate about the main difference between gas and oil field development**
- **Trainees discuss and answer the following questions individually or in group of 2/3:**
  - What is the main difference between gas and oil field developments?
  - Why is a production plateau needed? How can we decide for the value of this plateau?
- **Object of the debate: to make a collective synthesis**
- **Timing: 10 min**



Gas project schedule



Gas field development: typical exploitation facilities



Gas field development: typical block diagram

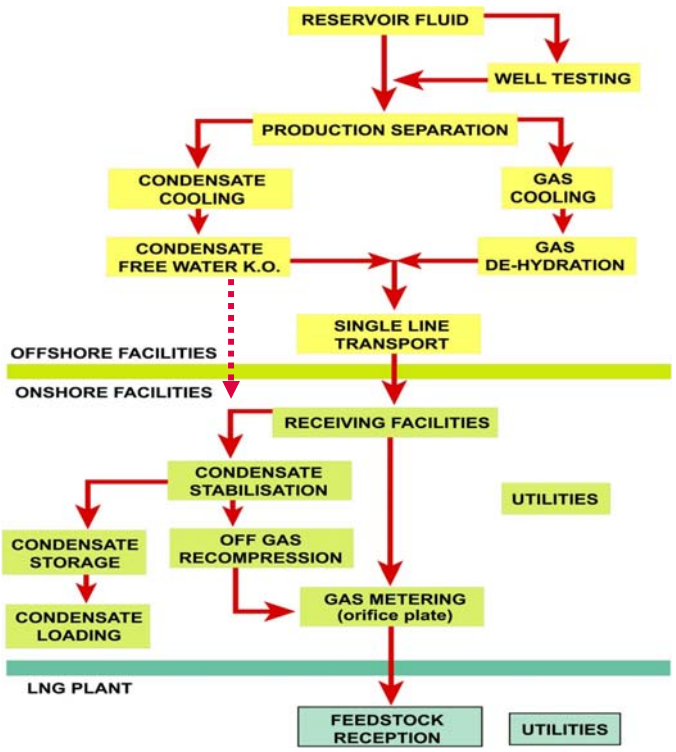
Production process

↓

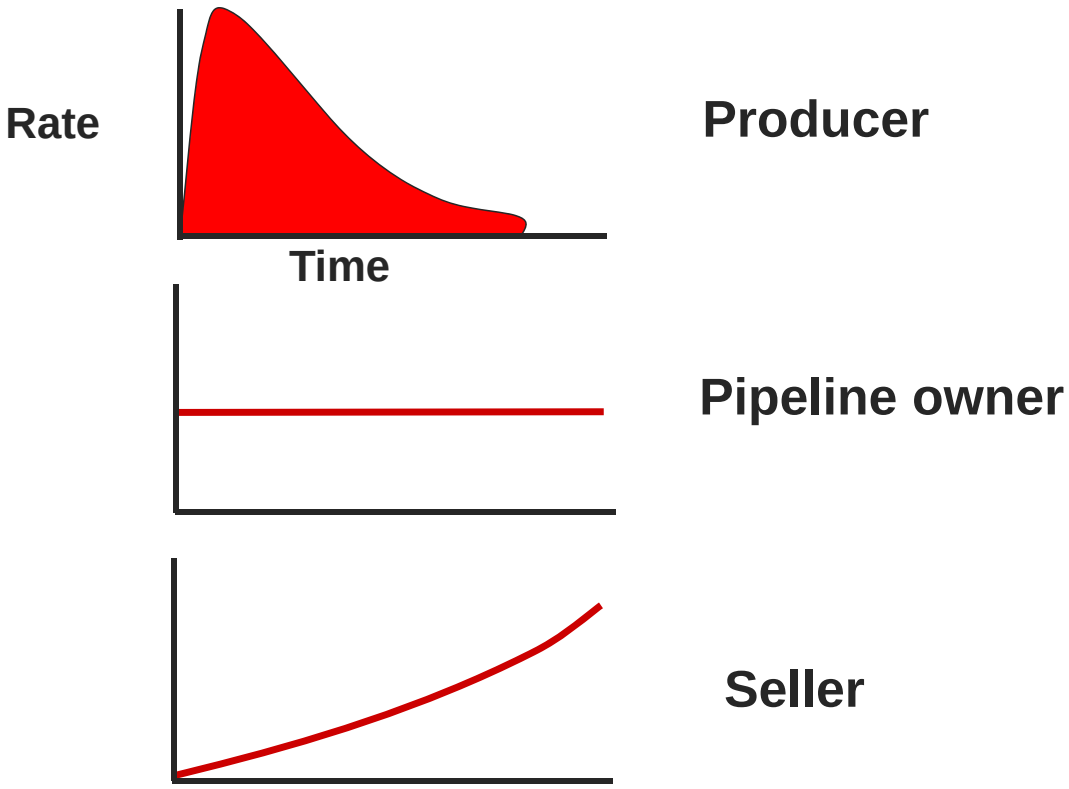
Gas plant (process)

↓

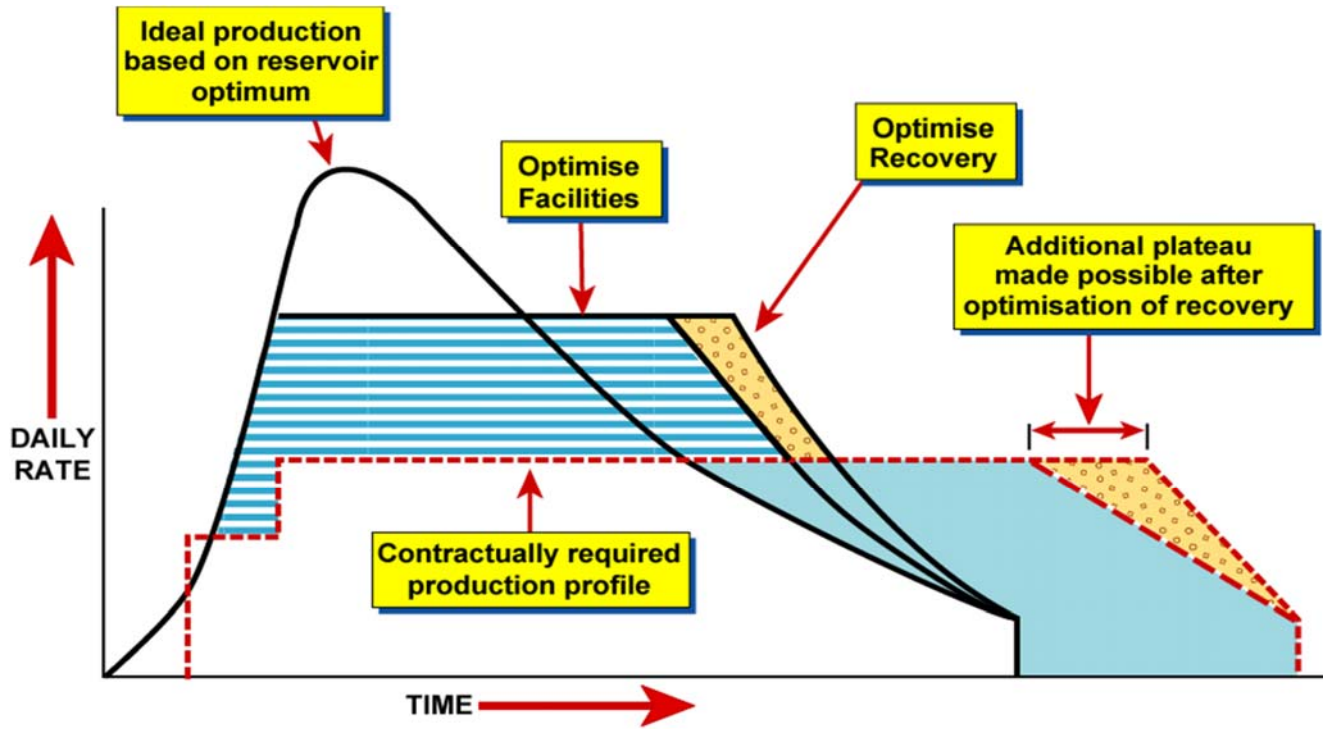
Pipeline or GNL plant



A production profile (gas field) is the result of a balance



Exploitation profile for a gas field constrained by the market



Issues to address before sanction

When planning a field development, the following technical questions should have been addressed:

- **Reservoir depletion strategy**
  - Natural depletion?
  - Water or gas injection to maintain reservoir pressure?
  - Artificial lift?
  - Production profile (plateau level and duration), Phased development?
- **Wells**
  - Completion strategy, well trajectories?
  - Surface or subsea, or both?
  - Pre-drilling? Type of rig?
- **Production**
  - Safety: field layout, grouping or separation of functions
  - Export: stand alone or tie-in to existing export system?
- **Project execution plan**
  - Construction yards availability in the area
  - Project execution schedule
  - Contractual strategy

Some conclusions…

- **There are uncertainties, part of development evaluations from Initial to FID (… and also after)**
- **Once the uncertainties have been addressed in detail at pre-project or new development phase, a Reservoir management plan can be established; among the objectives, it issues a monitoring program (what and when)**
- **The concept selection stage may save the significant costs**
- **The pre-project stage is equal marginal cost saving**

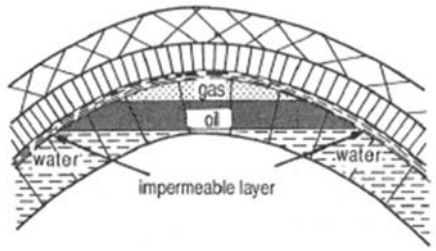
- **Imagination and innovation can help to:**
  - Prevent decline
  - Increase reserves

Development decision, business processes & economics

- 3. Key issues:
  2G& R - RMP & RmP
  … other HSEQ, economics,

Key issues

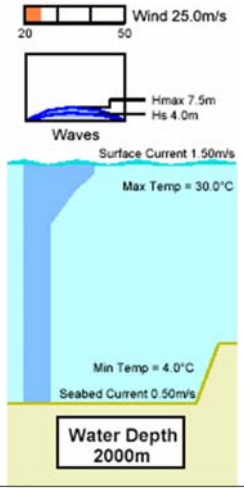
2G & Reservoir



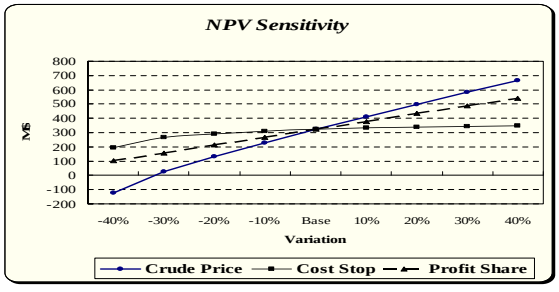
Contract



Health Safety Environmental



Economy



Key issues

Health, Safety & Environment

- **Technological risks:**
  - Generated by toxic, flammable, explosive substances
  - Risks concerning individuals, environment, integrity of installations and production
- **Occupational risks:**
  - Injuries or fatalities caused by the hazards in the workplace and the nature of the work
- **EBS & EIA**
  - Environmental baseline study
  - Environmental impact assessment







Key issues

Contracts

- **Possibility of long term contractual strategies (authorities, contractors, commercial)?**
- **Constrained timing (development and start of production)**
- **Possibility of a phased development?**
- **Use of associated gas**
- **Fiscal terms**
- **Local content**
- **Etc.**

Reservoir management plan

- **The RMP is a "Road Map" for the Asset team**
- **It is a synthetic document:**
  - Treating all the main aspects for geosciences
    - in particular reservoir engineering
    - and contribution / data on other domains (drilling, economics, field operations, ..)
  - Associated to the field development plan(s)
  - Generally addressed in pre-project phase
  - It pinpoints:
    - The project objectives
    - The project status and uncertainties
    - The future strategy, planning and needs (development strategy, data acquisition, monitoring, nearby exploration stakes …)
- **It should be approved by Management at headquarters and be used as a "law enforcement" document within the subsidiary**

Reservoir management plan example – overall content

1	**Executive summary**	***To catch through some (but not few) pages a good overview of the Development***
1.1	Objective of the **Field** RMP	General elements on Devlpt…
1.2	Goals and strategy	Devlt objectives, summary reserves/prod expectations, main equipt (PF, facilities, wells,..)
1.3	Field and development description	Location, association, broad geological data, reservoir data…
1.4	Field data base	General elements : reservoirs / fluid characteristics / 2P HcIIP-Prod. Profiles & reserves…
1.5	Uncertainties and development risks	Uncertainties studies done, Range 1P / 3P on HcIIP & Reserves , impacting parameters…
1.6	Production management	Ramp-up/plateau/decline mngt strategies & constraints, WI/GI SU vs Prod, wells potential, WO, WSO
1.7	Well recommendations	Status, recommendations together detail engineering, sequence priorities vs appraisal to do
1.8	Data acquisition and studies	Data acquisition philosophy / strategy vs remaining uncertainties, …, possible extension, …
1.9	Human resources	Prepare / anticipate GSR staffing according to project evolution
2	**General data**	***Details on however General information & Data***
2.1	Regional context	Geographical context, surrounding activities,
2.2	**Field** history	Year after year events, acquisition, studies, evaluations, decisions, realizations, ….
3	**Main constraints**	***Details on however General information & Data***
3.1	Economical environment	Fluids valorization data (vs reference fluids, gas LNG, …
3.2	Legal and ecological constraints	Permitting history; policy on gas flaring, water production treatment & dumping, …
3.3	Production constraints	Current / future data on exploitation design production/injection/export liquid/gas …
3.4	Reservoir constraints	Technical / economical limits for wells …
3.5	Drilling/Completion constraints	Rig & number types, Prod & Inj. completion type (sand control, smart, multi-reservoir …
3.6	Layout constraints	Overall data on exploitation, PF, Subsea cluster / Pipes / network, buoys,

Reservoir management plan example – overall content

4	**Field reservoir description**	***Details on GSR evaluation process/tools used - not "metier studies" referenced in biblio***
4.1	Regional setting	Info on geological / structural system regional & reservoir scale ..
4.2	Geophysics	Acquisition / Methodology Interpretation : picking / wells calibration, Seismic attributes …
4.3	Geology	Data used wells/logs/core .. Methodology Geological model building
4.4	Fluid properties	AMI / Main characteristics (Hc, water,..) / continuity …
4.5	Initial fluid contacts and intra-reservoir communic	AMI main data / continuity inter-intra reservoir
4.6	Petrophysics	AMI fit logs/cores/ well test– data by environment / reservoir/ Layers / Rock type SCAL polyphasic Kr, Cr
4.7	Volumes in place & reserves	Methodology – 2P figures filed / reservoir – Rec. factors
4.8	Historical field performance	Current status : wells / performances / maps & field production curves O/G/W …
5	**Reservoir modelling**	***Details on static & dynamic models***
5.1	Geological model	Gridding/layering, Petrophysical modelling and methodology model infilling …
5.2	Dynamic model	Software BO/Compo…, Gridding-Layering vs static / averaging-upscaling / aquifer / PVT / History Matching
6	**Subsurface development key points**	***Details***
6.1	Development strategy	Key points on development / sequence / objectives (rates/plateau, ..)
6.2	Well performance prediction	Expected Productivity / injectivity …
6.3	Gas-lift	Needs wells activation, Electrical Submersible Pump, …
6.4	Water injection	Capacities, Sulfate Removal Unit, Prod.Water Re-Inj., ..
6.5	Production and injection profiles	Capacities, forecasts P/I curves / 2P
6.6	Gas management	Specific concerns, LNG, re-injection, …
6.7	Drilling and completion methods	P/WI/GI Wells names vs reservoir, targets, typical architectures, completion - smart
6.8	Well sequence	Rigs, priorities appraisal objectives, Pro vs Inj, expected acquisition to adjust sequence / pattern
6.9	Upsides	Possibility infill, neighbor undeveloped reservoir, action plan to valorize,,
6.10	Enhanced oil recovery potential	Identification, action plan (stakes, acquisition, studies, ..)

Reservoir management plan example – overall content

7	**Detailed well pattern and sequence**	***Details reservoir / reservoir, targets, …***
7.1	General description	Wells locations maps/ drilling sequence / ..
7.2	RIII Field Reservoir	Details reservoir - wells P/I targets& pattern / uncertainties drilling drainage efficiency/
7.3	RIII Field Reservoirs	*Ctd* observation wells, Pilot Hole wells, mitigation plan in case of unexpected results
7.4	RIV Field Reservoir	*Ctd*
7.5	RIV Field	x
8	**Data acquisition and field monitoring.**	***Forecasts / preparation of field / wells monitoring***
8.1	Drilling Fluid	Type, cuttings management
8.2	Pilot Holes	Needs / location to confirm development strategy pattern / reduce remaining uncertainties
8.3	Measurements While Drilling	Planned Above / In reservoir sections
8.4	Coring	Status & needs, complementary …
8.5	Wireline/TLC/CT Logging	Acquisition type, High Resolution tools, Well Seismic, MDT/RFT, …
8.6	Cased Hole Logging	Acquisition initial/future, Production Logging Tools, Saturation Tools, …
8.7	Well Tests/Interference Tests	Initial, future strategy, Interference –communication anisotropies H/V
8.8	Time Lapse (4D) Seismic	Base line, acquisition frequency, surface, OceanBottomCable /OBSeismic, permanent devices
8.9	Production Monitoring/Well Allocation	Metering devices, test separator, MPFlowMeter, wells / risers / surface …Reminders on allocation
8.10	Bottom Hole Data	P/T permanent/WL, optical fiber, …
8.11	Injection Monitoring and Tracers	P/T, optical fiber / profiles , tracer technology preparation/planning ..
9	**Subsurface risk management**	***Details***
9.1	Uncertainties on the Accumulation	Static - Methodology on current ranges / impacting parameters geometry/contacts/Petro/ ….
9.2	Uncertainties on the Reserves	Dynamic - Methodology on current ranges / impacting parameters geometry/contacts/Petro/ ….
9.3	Other Development Risks	Risks on wells performance (Skin, scales, wax, …), poor/bad allocations, OPN/FO risks unexpected shortfalls
	List of Figures	
	List of Tables	
	Bibliographical References	Specialties/Synthesis/detailed GSR Studies, FDP, major FO/DC studies references

Monitoring prevision PREMONIT example – overall content

1. Subject of the PREMONIT 4
2. Main modifications compared to previous version 4
3. Short presentation of the field, incl. history and uncertainties 4
3.1 Location 4
3.2 Development plan 4
3.2.1 Complementary Development R'D' 5
3.3 Reservoir description and communication 7
3.4 Summary of operations history 8
3.5 Unknown and residual uncertainties description, stakes evaluation 8
3.5.1 Static uncertainties 8
3.5.2 Dynamic uncertainties 8
4. Principles and strategy of monitoring and data acquisition 8
5. Specific equipments of reservoir monitoring 9
5.1 Down hole permanent monitoring 9
5.2 Sand detection 9
5.3 Metering 9
5.4 Specifics of the installations which may impact data acquisition and testing program 9
6. Data acquisition in development wells 10
6.1 Logging while drilling (MWD, LWD, LOT ...) 10
6.2 Coring 10
6.3 Open-hole and cased-hole logs 10
6.4 Initial well-tests 10
6.5 Recapitulative table 10
7. Multi-year program of wells' acquisition 10
7.1 Production logging 10
7.2 Pressure build-up and fall-off 11
7.3 Fluids sampling 11
8. Field monitoring program 11
8.1 Tracing campaign 11
8.2 4D seismic 11
8.3 Well bywell review: operation interest and opportunities 11
9. Data management 14
10. Elements for costs evaluation (CAPEX / OPEX) and MAP with regard to the data acquisition program 14
11. Summary of sizing elements to be included in the SOR (PREMONIT V2 of RMP) .. 14

Notes

Development decision, business processes & economics

- 4. Project economy

Investment workflow





Idea

- Building a house

Analysis

- On the beach
- Down town
- High technology
- Straw or brick

Decision

- Invest
- Drop
- Wait





Project economic evaluation

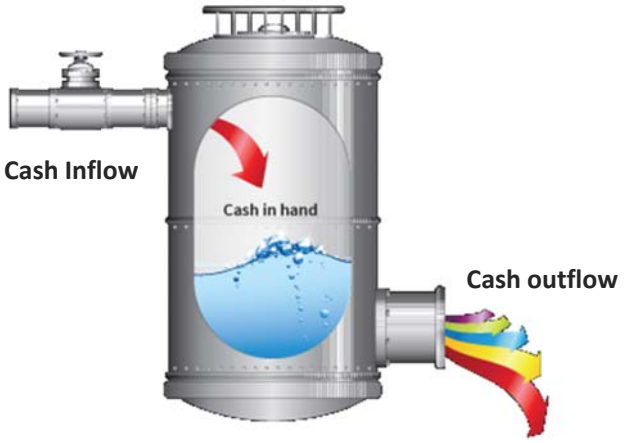
- **Objectives:**
  - To estimate the monetary value of a project & to analyze the project value drivers
  - To compare technical alternatives
  - To evaluate tenders and to prepare negotiation positions
  - To forecast cash flows and to prepare budgets
  - To track on going project performances versus budget and forecast
- **Risks analysis and sensitivities**
- **A risk analysis is performed to assess the impact of the potential variations of the key factors on the economic value of the project (sensitivities)**
- **Major risks and impact on project value:**
  - Reservoir uncertainties ➔ Reserves?
  - New technology ➔ Costs? Added value?
  - New technology ➔ Risks? Production delay?
  - Low oil prices ➔ Project value

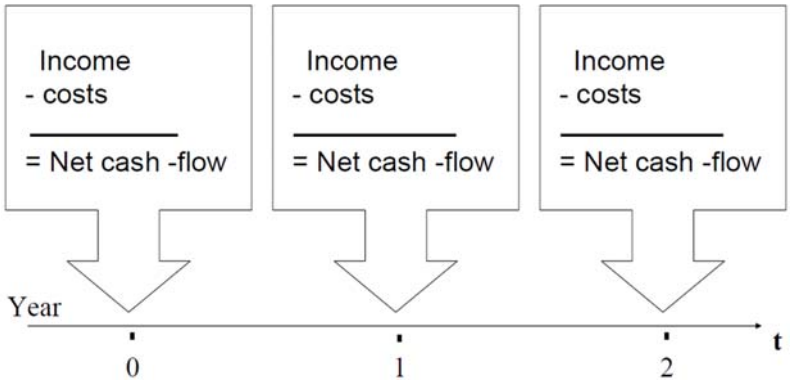
Economic criteria

Analysis

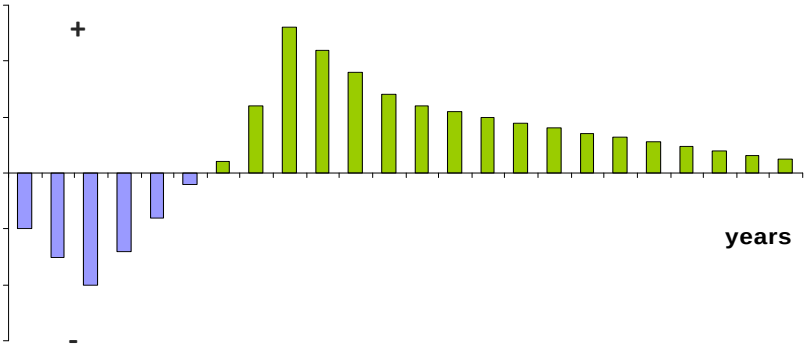
- **Main criteria**
  - Net Present Value (a) [NPV a]
  - Internal Rate of Return [IRR]
  - Pay-Out Time [POT]
  - Maximum Financial Exposure [MFE]
  - Technical cost per barrel
- **Other criteria**
  - Breakeven oil price (Oil price at which Project NPV (0) = 0)
  - Technical cost per barrel Capital Profitability Index (a) [CPI a]
- **There is no unique and ideal economic criteria. Decisions are taken by examining a set of different criteria to better evaluate the economic potential of a given project.**
- **It is important to look at sensitivities to certain technical and economical parameters**

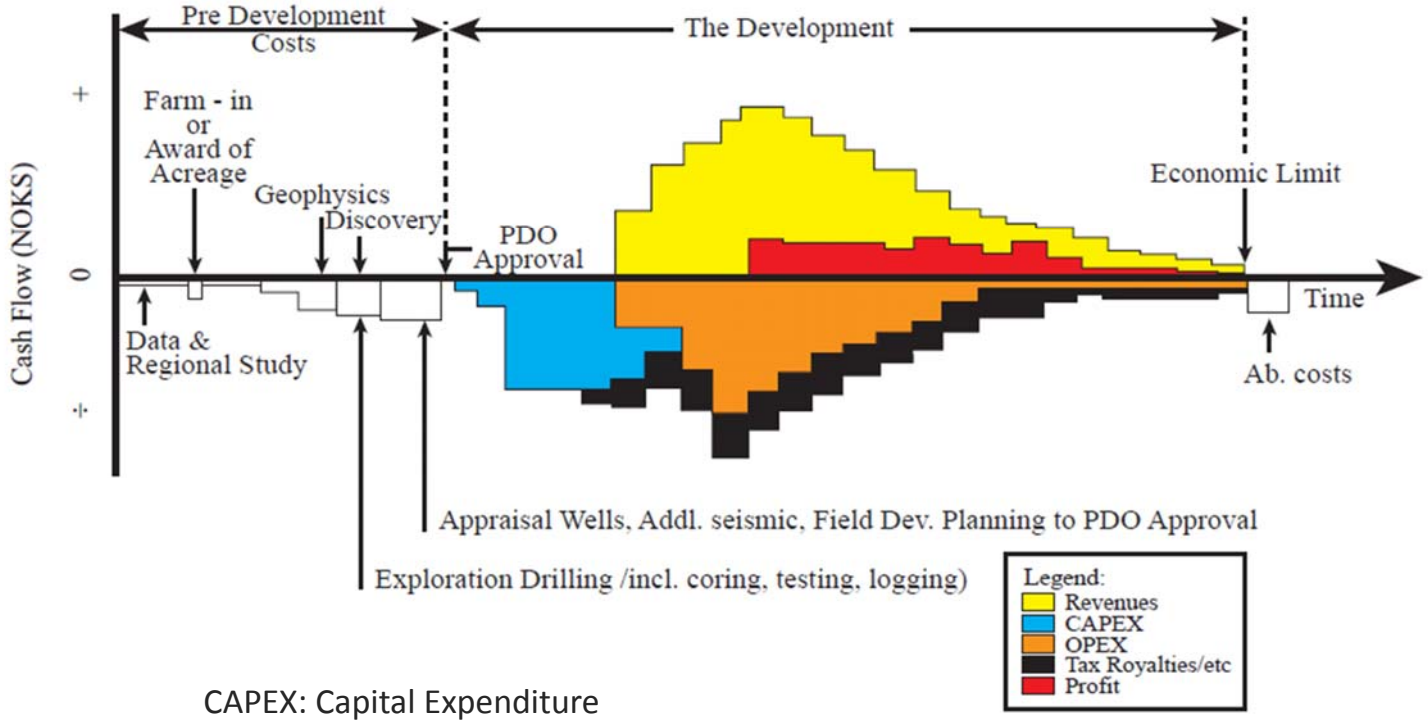
Cash flow





Yearly cash flow





CAPEX: Capital Expenditure
OPEX: Operational Expenditure

Time value of money

- **Can we just add up inflow and out flow for decision making?**

- **What are the parameters?**
  - Inflation
  - Time value of money
  - Uncertainty (risk)

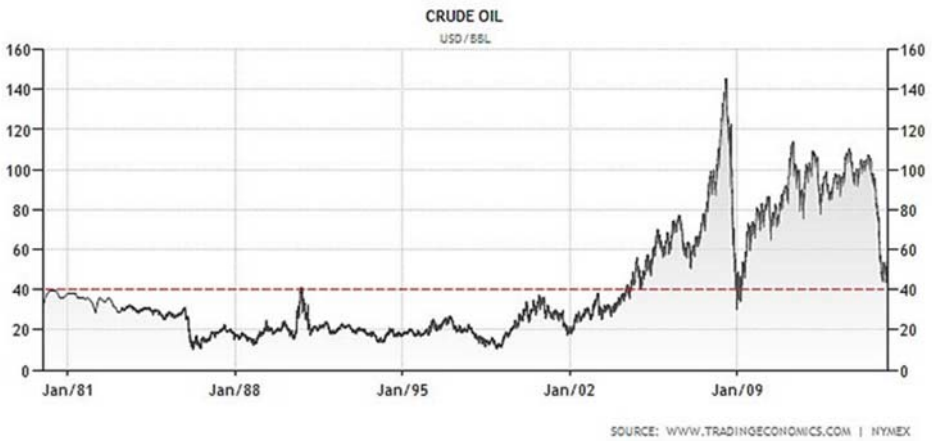






Uncertainties

- **Exchange rates:**
  - Most companies in Europe base their exchange rate forecast on the analysis made by OECD or other such institutions
- **Inflation rates:**
  - It is common to base the inflation forecast on the analysis made by OECD
- **Oil price**



Economy concepts

Observation

- **Principle**: watching a video about Economy concepts
- **Object of the game**: to see *Definition of Cash Flow, NPV, IRR …*
- **Timing**: 10’



- **Bank deposit:** $ 100
- **Annual interest rate:** 10 %
- **After 1 year:** V1 = \$100 * (1 + 0.10) = \$110.0
- **After 2 years:** V2 = \$110 * (1 + 0.10)
  = \$100 * (1 + 0.10)*(1 + 0.10)
  = \$100 * $(1 + 0.10)^2$ = \$121.0
- **After 3 years:** V3 = \$121*(1 + 0.10)
  = \$100*$(1 + 0.10)^3$ = \$133.1

V_0

- The amount of money we put in the bank today

V_n

- The amount of money we can take out of the bank after n years

a

- A fixed interest rate in % per year

Relation

- $V_n = V_0 (1 + a)^n$



- Calculate separately the present value of all the cashflow elements

Time	0	1	2
Cash Flow	-100	80	70
	-100/(1+0,06)^0	80/(1+0.06)^1	70/(1+0.06)^2
Present Value	-100	75	62

- Add together the discounted cash-flow elements

NPV = -100 + 75 + 62 = 37



Discounting

Discounting allows to measure the future depreciation, compared to present

Components of discounting

X % → **Risk bonus**
- Remuneration of the risk
- Depends on the project (and its environment)

+

C % → **Cost of time**
- Remuneration of privation of immediate availability
- Does not depend on the project

⇨ **Discount rate "a" is arbitrarily chosen by the investor**

According to a survey by Wood MacKenzie to upstream companies, the size of the discount rate was just over 11 %, the range being from 7 % up to 22 %.

Present Value & Net Present Value (NPV)

$$V_0 = \frac{V_n}{(1+a)^n}$$

V_0: present value
V_n: value @ year « n »
a: discount rate

Example: V_n = 1 million \$, n = 10 years and a = 10 %

➔ V_0 = 0,385 million \$

NPV = Cumulative yearly discounted cash flows

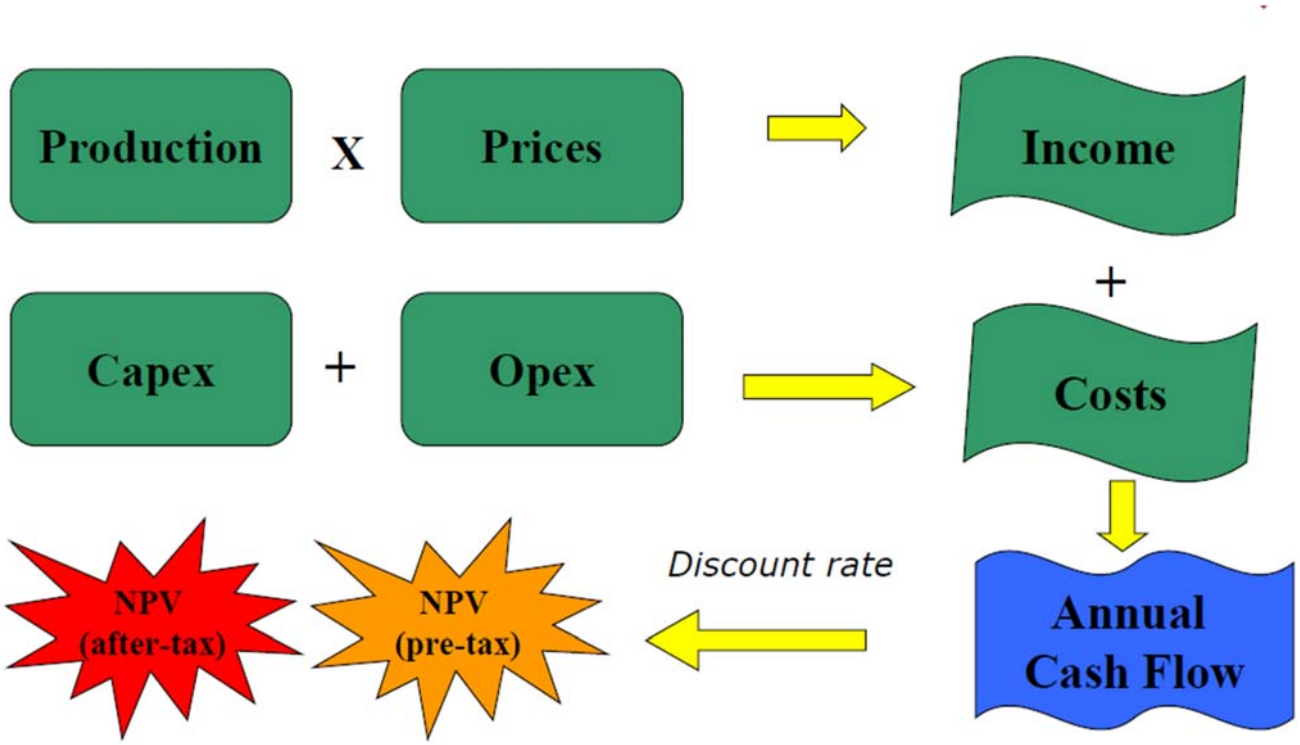
$$NPV(a) = \sum_{k=1}^{k=n} \frac{F_k}{(1+a)^k}$$

NPV: Net Present Value
a: Discount rate
n: Total nb of years
F_k: Cash flow for year k

PI (Profitability Index)

$$PI = \frac{\text{Future PV (a)}}{\sum \text{Discounted Invest. a \%}} = \frac{\text{PV of Cash Inflow}}{\text{PV of Cash Outflow}}$$

Analysis workflow



Economic result analysis

- **NPV > 0; The return > discount rate and the project is profitable *(best alternative use of your money)***
- **NPV = 0; The return = discount rate**
- **NPV < 0; The return < discount rate *(other alternative uses of your money is better)***

Calculation of the NPV

Exercise

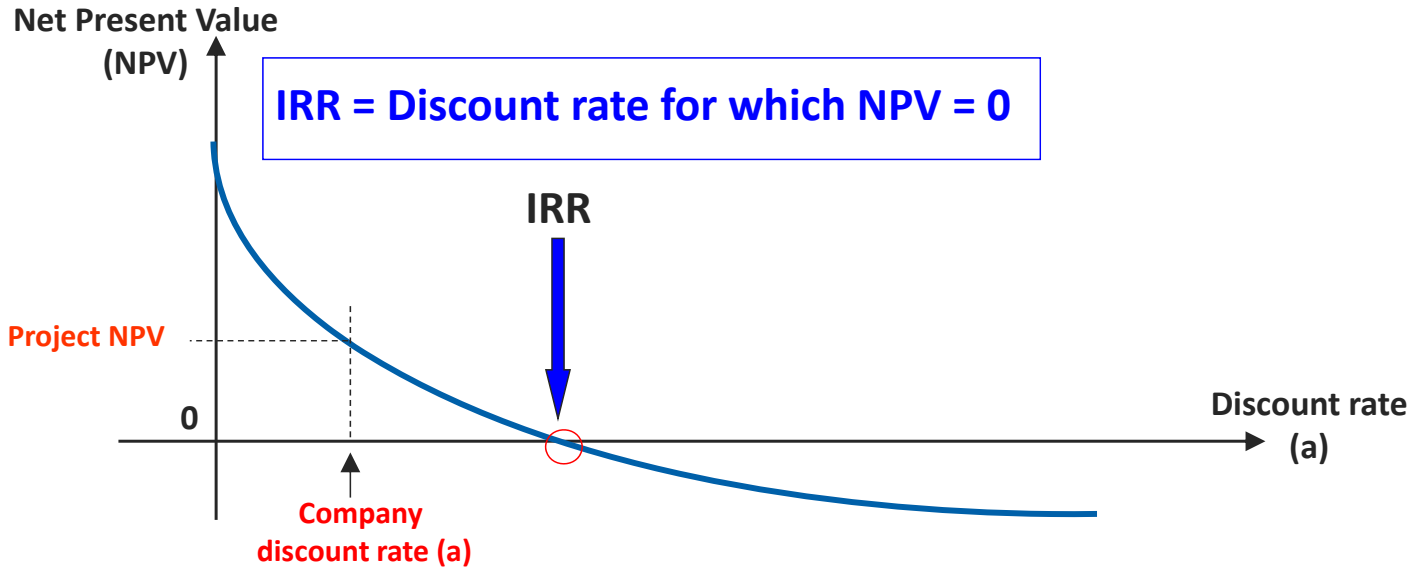
- **Trainee: calculate the NPV of the exercise for different discount rates**
- **Questions:**
  - What do you think about the discount rate at which NPV becomes zero?
  - What do they think about this value?
- **Objective:**
  - Calculation and application of Cash Flow, NPV
  - To be ready to see the IRR in next section
- **Timing:**
  - Calculation 20'
  - Solution and discussion 10'



Internal rate of return & value creation

Dsc rate %	Year 0	Year 1	Year 2	NPV
	-200	120	140	
0				
5				
10				
15				
18.5				
20				
25				

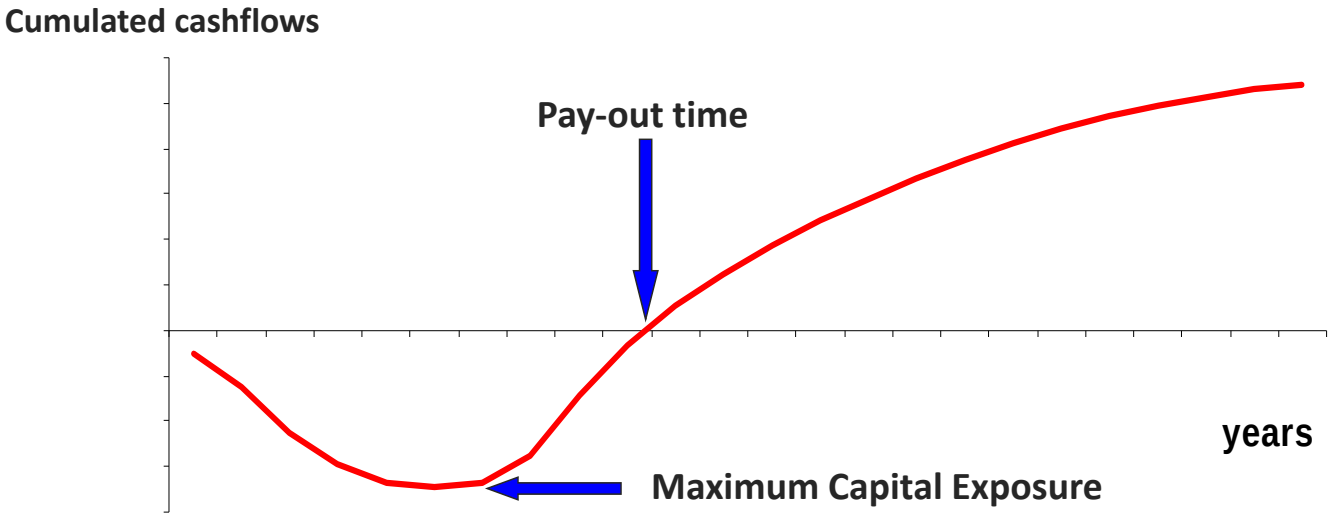
Internal rate of return & value creation



Value is created if:

- **Project NPV(a) > 0**
- **Project IRR > Company discount rate**

Pay-out time and maximum capital exposure

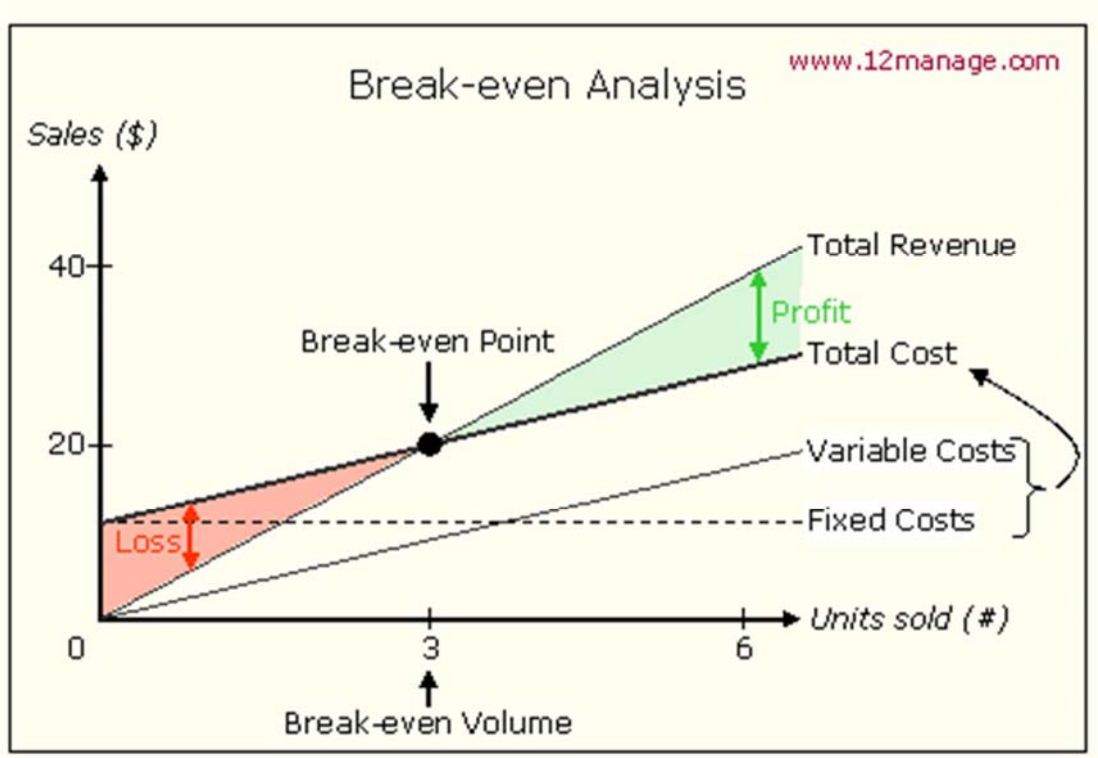


- **Pay-out:**
  - Period of time at the end of which the cumulative net revenues equal the total expenditures
  - Essentially, it is the time required to get the investment back
  - It does not take the time value of the money into account. One can calculate a discounted pay-out time if required

- **Maximum capital exposure:**
  - It is the maximum negative value of the cumulated cashflows
  - Generally, it occurs during the First Oil year

Break even point

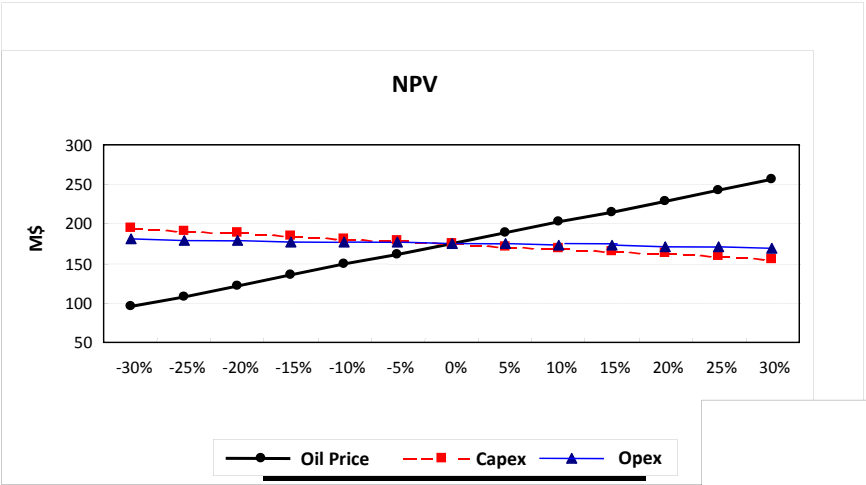
- **Break-even point is the number of units (N) produced that make zero profit at a known price.**



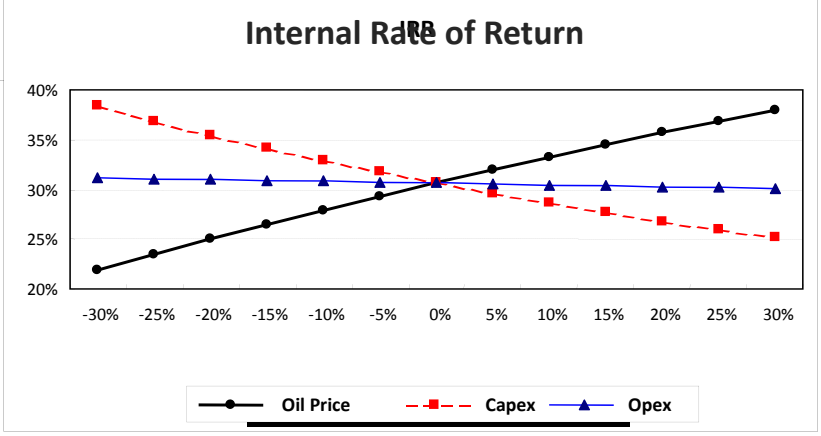
- **Technical cost per barrel: sum of PV of CAPEX and OPEX divided by Total N of barrels**

Example of sensitivity analyses

Net Present Value (a)



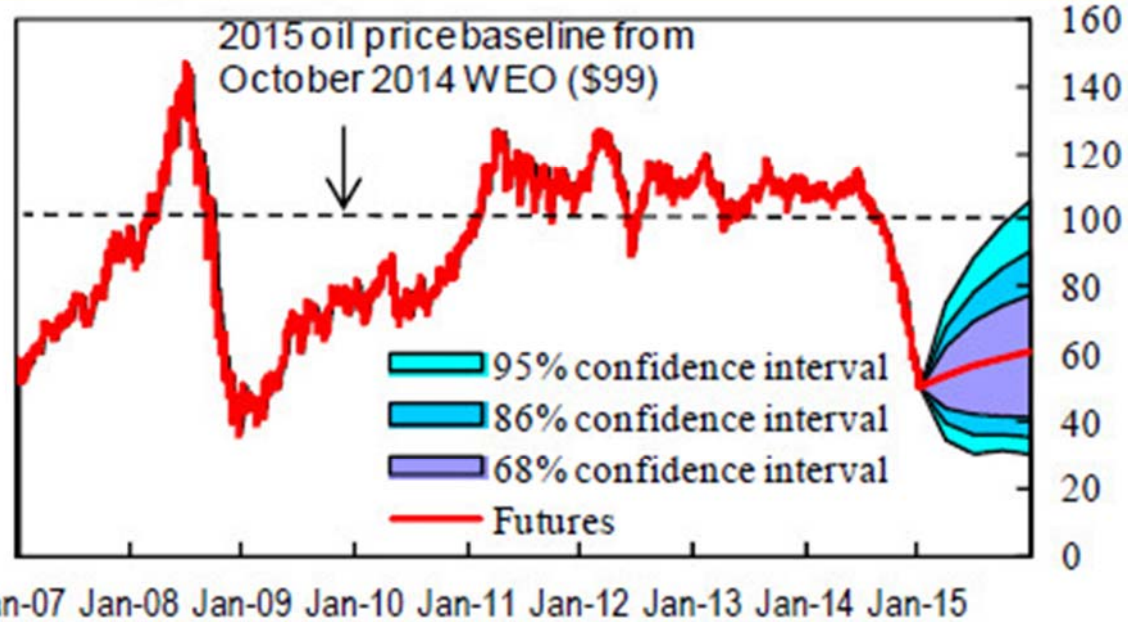
Internal Rate of Return



Development decision, business processes & economics

- 5. Cost examples

Figure 1. Oil Price Prospects[1]
(U.S. dollars per barrel)



Sources: Bloomberg; and IMF Research Dept. Commodities team calculations.
[1]Derived from prices of Brent futures and options on Jan 7, 2015.

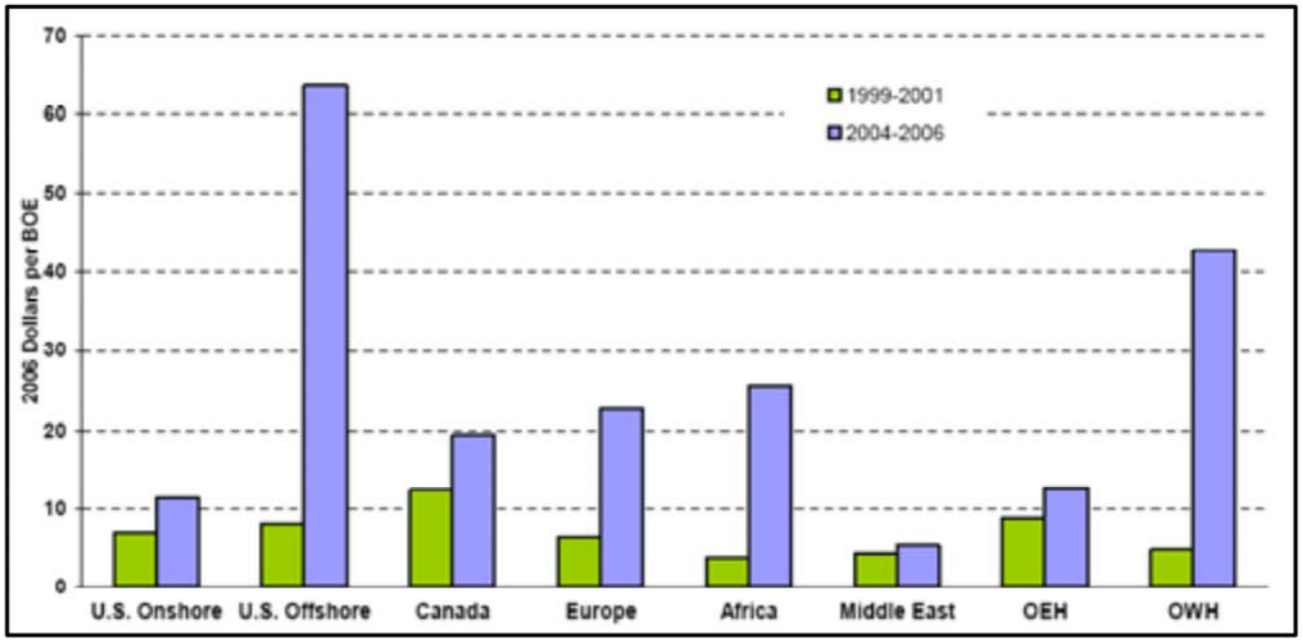
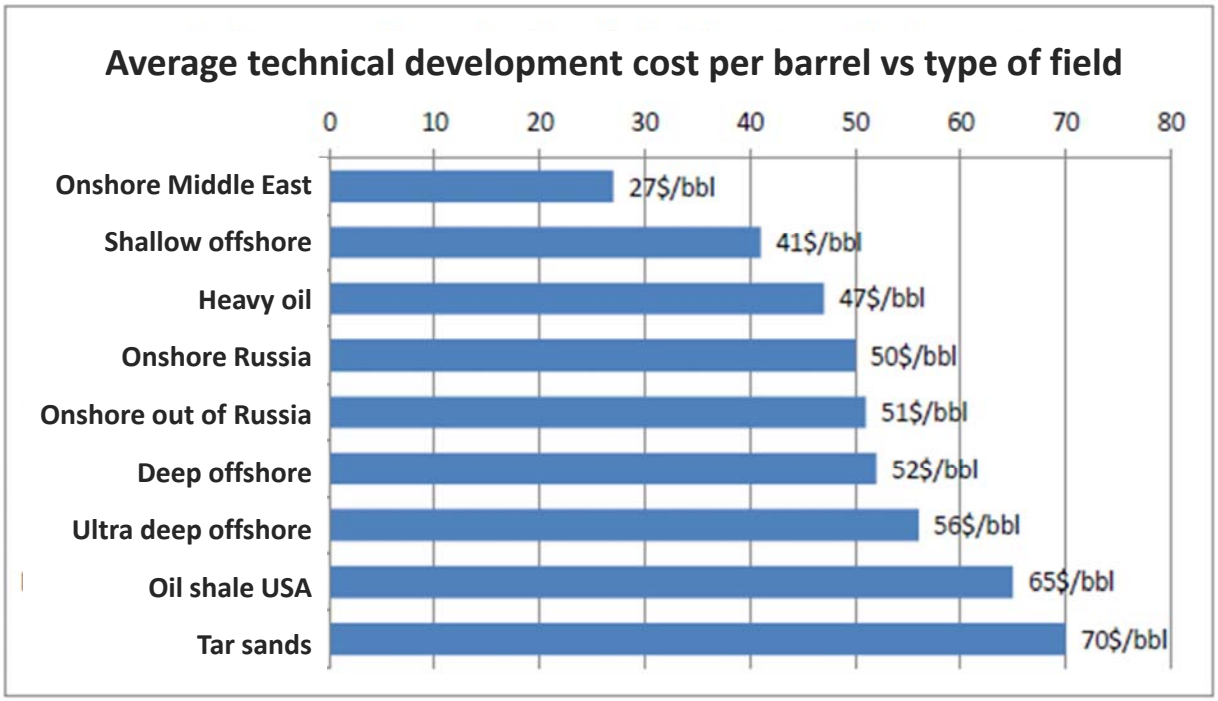


Fig. 5 – Exploration cost by region, 1991–2001 & 2004-2005, [4]

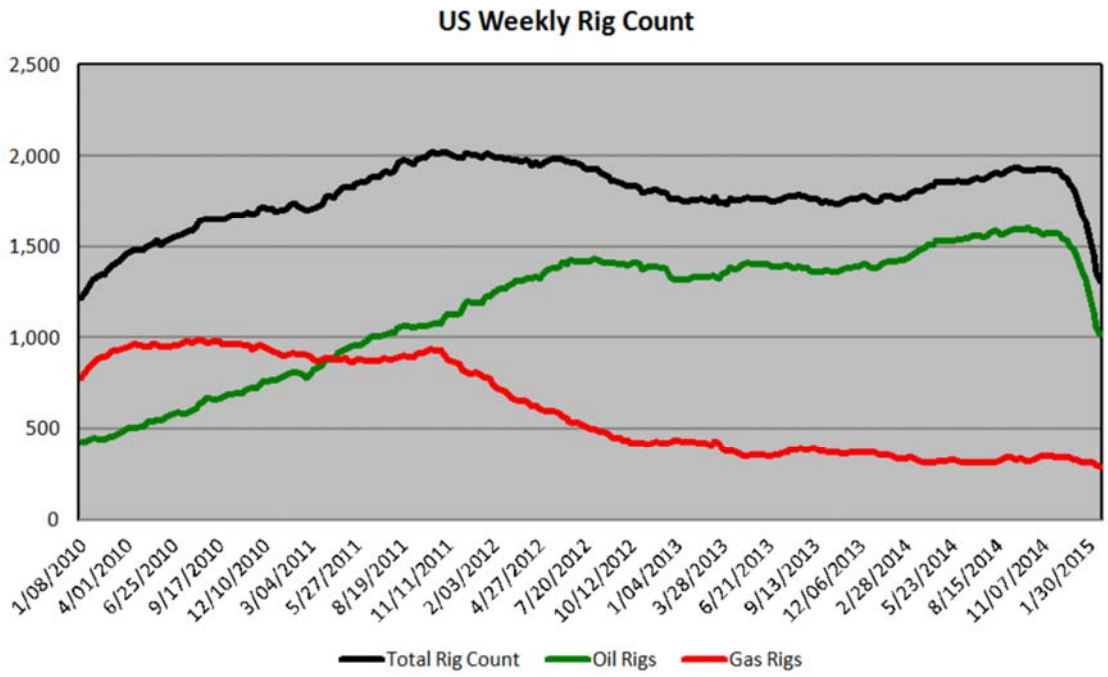
Energy Information Administration (EIA)

Current field development: technical costs



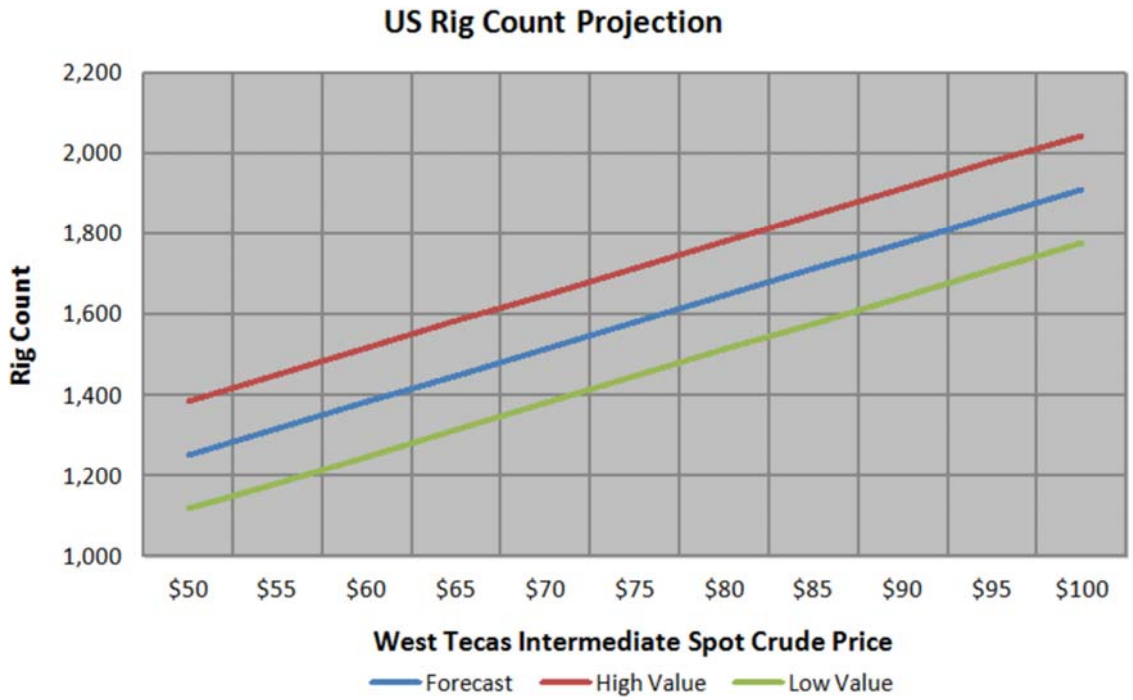
courtesy POLEAVENIA Geosciences Innovation Valley *Jan2015*

Number of active drilling rigs



http://www.petrostrategies.org/

Number of active drilling rigs



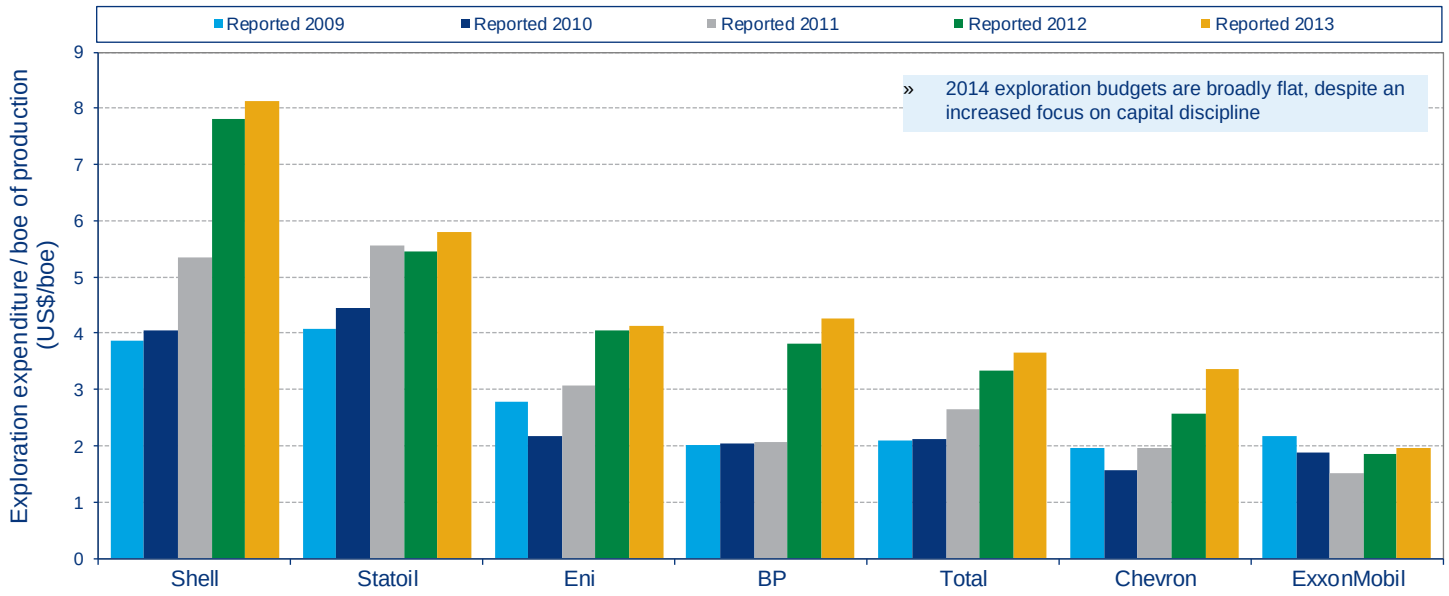
http://www.petrostrategies.org/

Majors companies

Exploration expenditures per barrel produced

» **Shell**'s recent aggressive exploration strategy is reflected in much higher levels of investment relative to the other supermajors; spend rose from US$4 billion in 2008 to over US$9 billion in 2013. **Statoil** and **Eni** have also turned to exploration to renew their portfolios.

» **ExxonMobil** bucks a trend of increasing exploration investment rates during the period; spend increased from US$2.3 billion in 2008 to US$2.9 billion in 2012 following the **XTO** acquisition, but is still only aroundIone-third that of **Shell**.



» 2014 exploration budgets are broadly flat, despite an increased focus on capital discipline

» **Total** and **BP** are refocusing on high-impact exploration, with budgets increasing butBP's n mbers are a so influenced by lower production due to theicompany's d vestment programme

Source : Wood Mackenzie

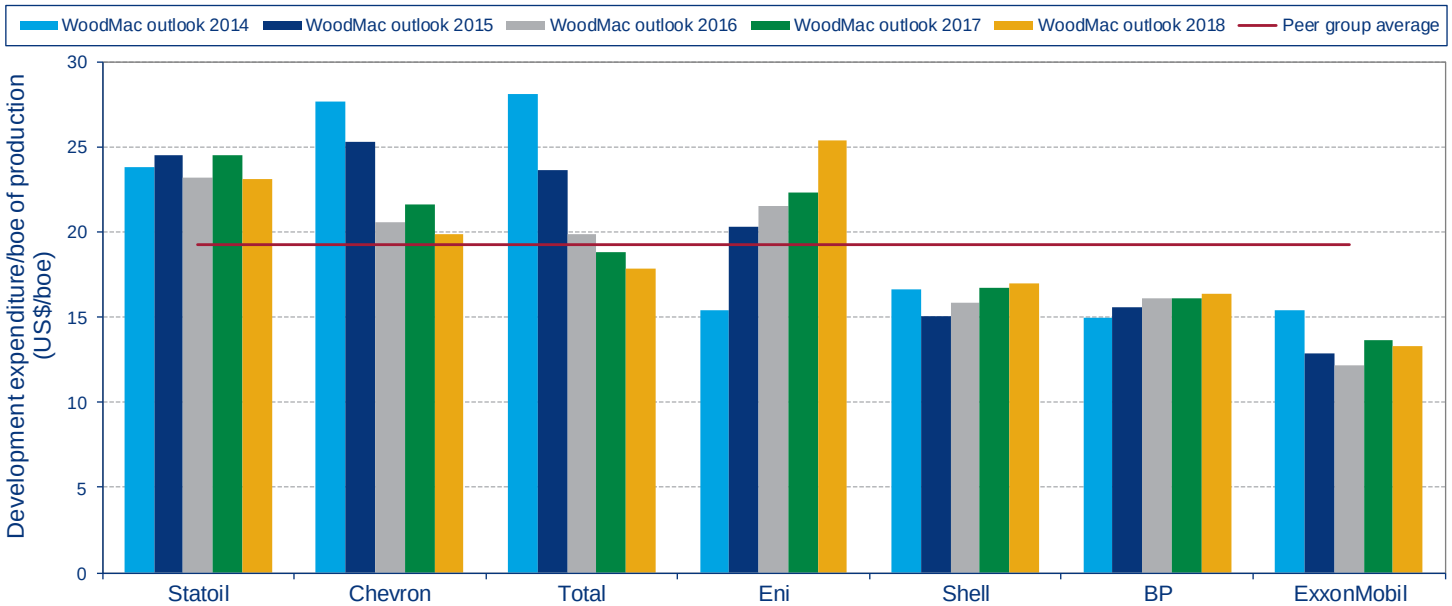
Majors: development investments

Investment (1) – WOODMAC outlook for development costs per boe

» **Chevron** will exit its capital intensive phase in 2017, when new projects such as Gorgon will drive strong cash flow growth. Firming up a new wave of developments will become increasingly important.

» **Total** is investing at the highest rate in 2014 but investment levels then trend downwards

» **ExxonMobil** will continue to invest at one of the lowest rates - uncons spend could be a big swing factor.



» **Statoil** is now opportunity rich, and will be investing at the highest rates in the peer group – even with recent projects being pushed back. The giant Johan Sverdrup conventional discovery will be an important focus.

» **Shell**'s development expenditure is picking up, driven by Australia, Nigeria and the US. However, it will be investing below the peer group average – a stark contrast to its pre 2010 profile.

» **BP**'s investment rate starts rising again near term after the divestments – but the shape of profile remains uncertain.

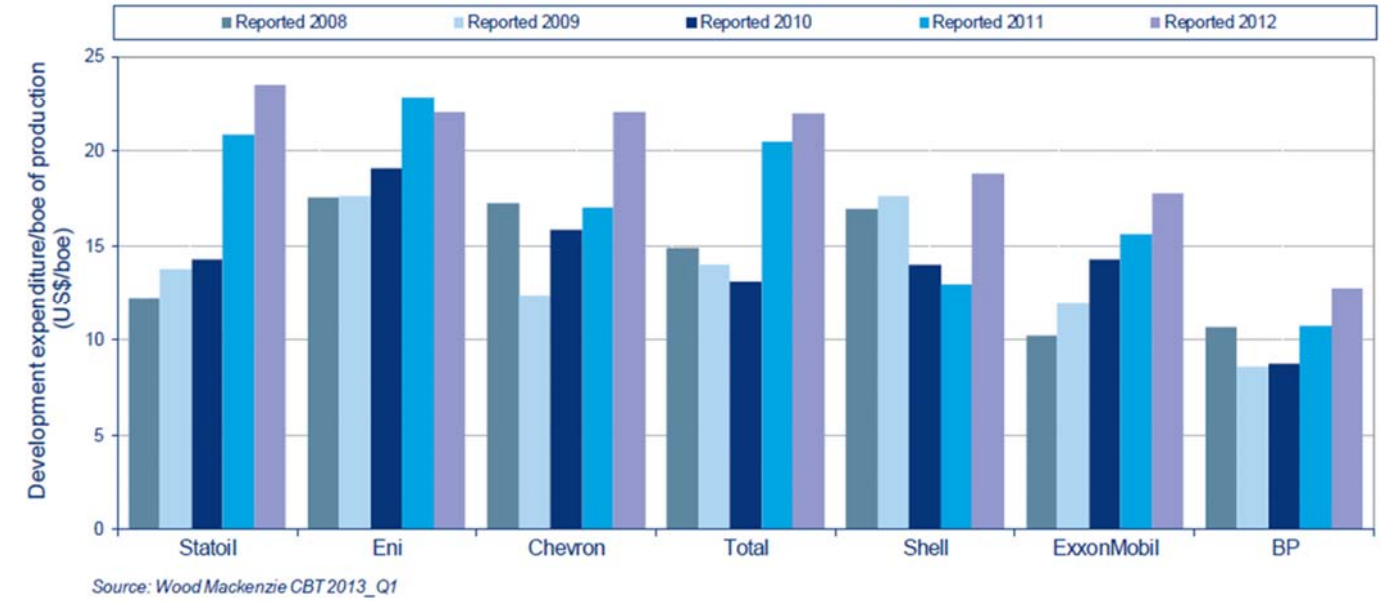
Majors companies

Development expenditures per barrel produced

› **Statoil**'s expenditure is increasing as it ramps up spend in Norway and unconventional developments in the US

› **Chevron** has increased investment to exploit a strong pipeline of newfield developments

› **ExxonMobil** has consistently increased development spend per unit of production during the period as it develops a new wave of mega projects and ramps up US unconventional spend



Source: Wood Mackenzie CBT 2013_Q1

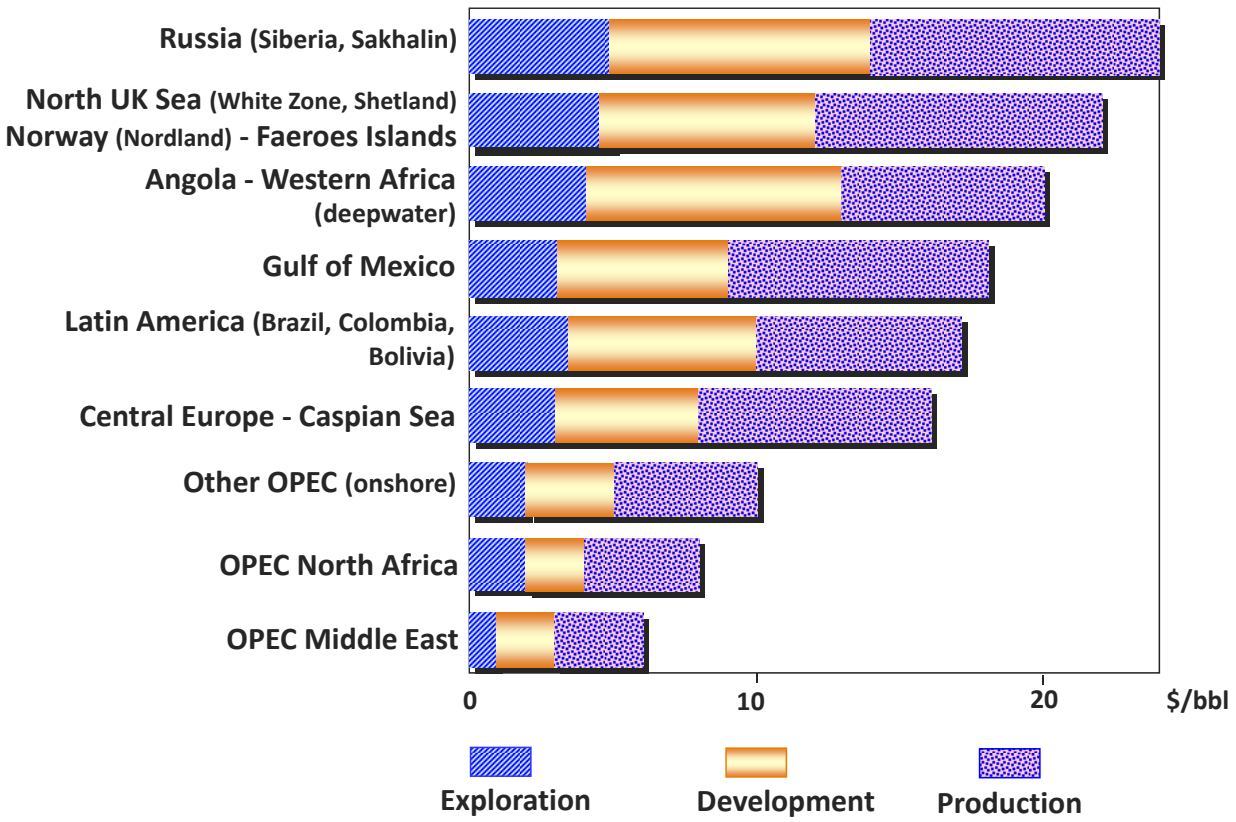
› **Eni** has been investing heavily in Kazakhstan and Africa as it seeks a return to production growth

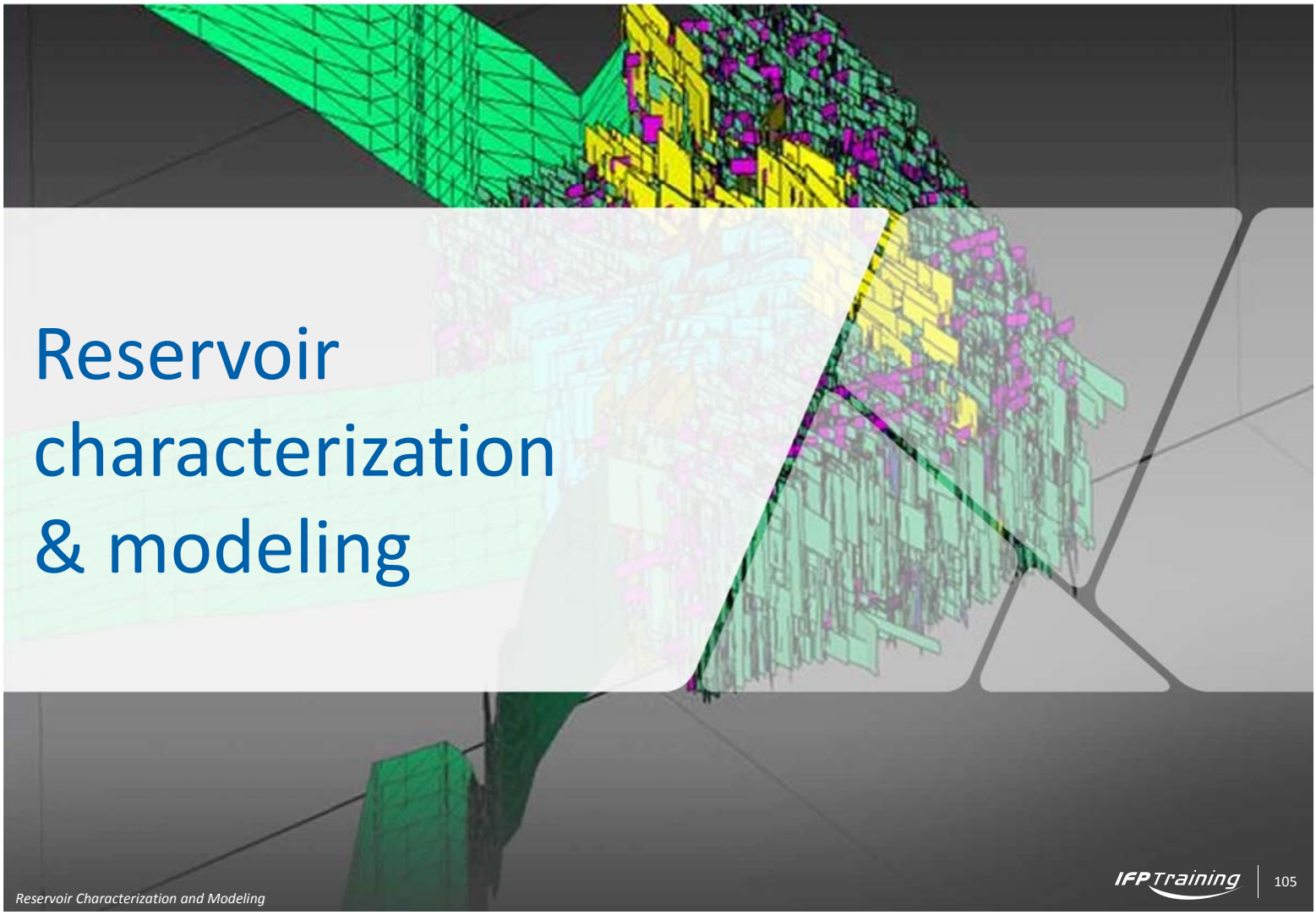
› **Total** has entered a capital intensive phase as it develops new long-life assets

› **BP**'s low investment rates is a large part due to more modest levels of development expenditure per unit of production in Russia

Field development

Technical costs





Reservoir characterization & modeling

Reservoir characterization & modeling

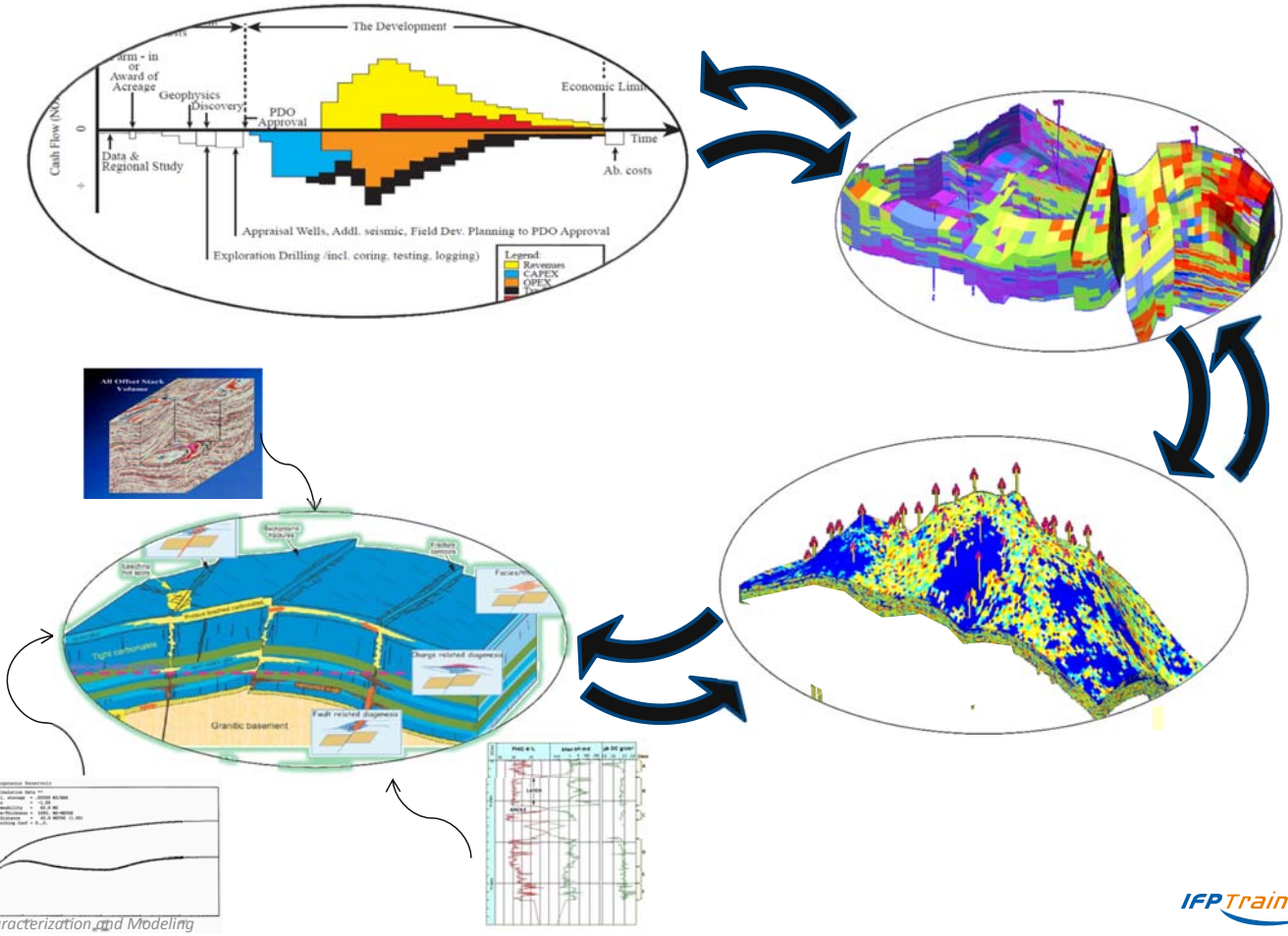
Outlines

1. Reservoir modeling objectives
2. Static data integration & geological modeling workflow
3. Geological modeling - Static and dynamic data
4. Reservoir heterogeneities
5. Reservoir uncertainties
6. Reservoir modeling

Reservoir characterization & modeling

- 1. Reservoir modeling objectives

Reservoir characterization & reservoir management?



Objectives of your company

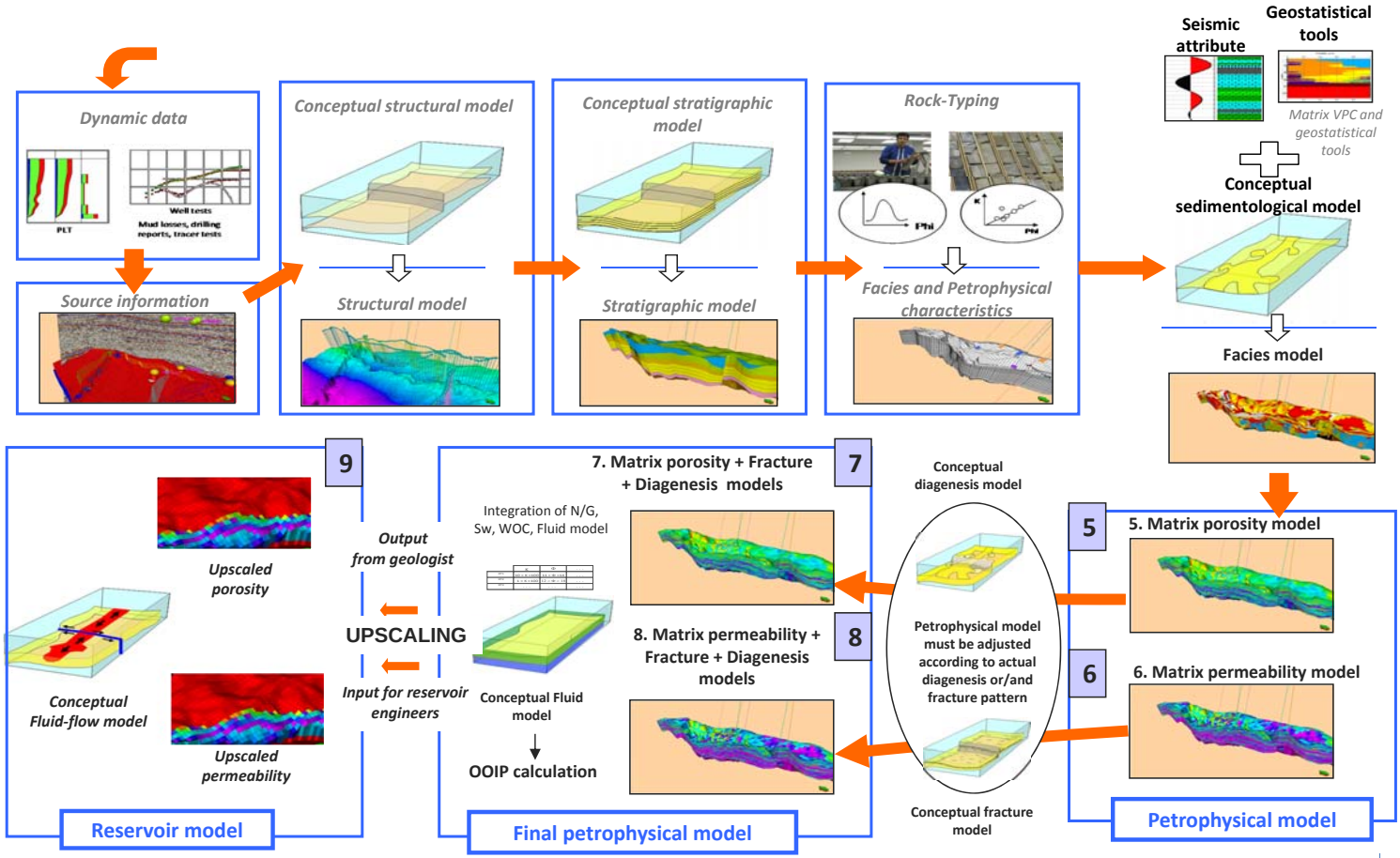
- **Main goal after a new discovery:**
  - To ensure the field development project is economically profitable
  - → **Plan adequate field development to optimize recovery**
- **Throughout field life:**
  - To acquire relevant information to monitor reservoir behavior
  - → **Use recorded information to optimize production recovery**

→ The proper way goes through reservoir modeling : → The right man is the reservoir engineer

- **The optimum profitability of a project requires knowledge of:**
  - The volume of in-place hydrocarbons
  - The recoverable reserves (several scenarios)
  - The expected well performance (daily production)

→ The proper way goes through geological modeling : → The right man is the reservoir geologist

How to build a reservoir model?



Geomodel vs reservoir model

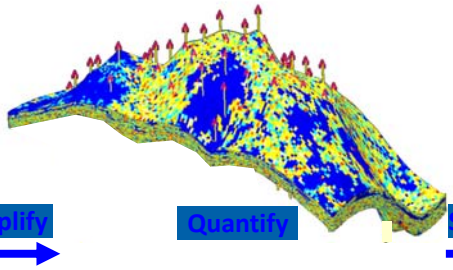
Characterize reservoir | Predict dynamic behavior

Reality

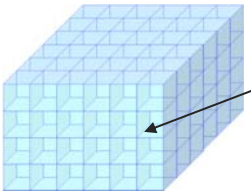


Simplify

Geological model
for static simulation



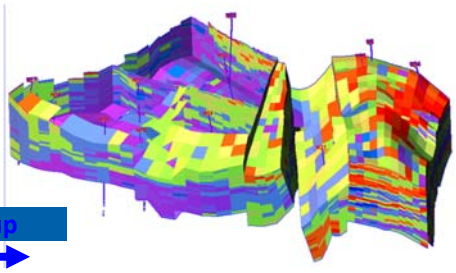
Quantify

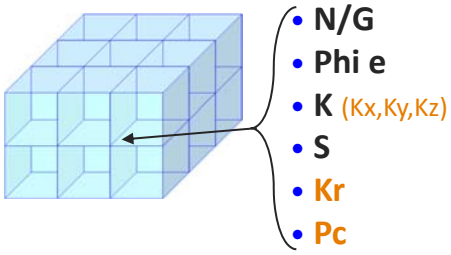


- Quantitative synthesis
- One model for each parameter:
  - To understand hydrocarbon spatial distribution
  - To calculate accumulations in place

Scale up

Reservoir model
for dynamic simulation





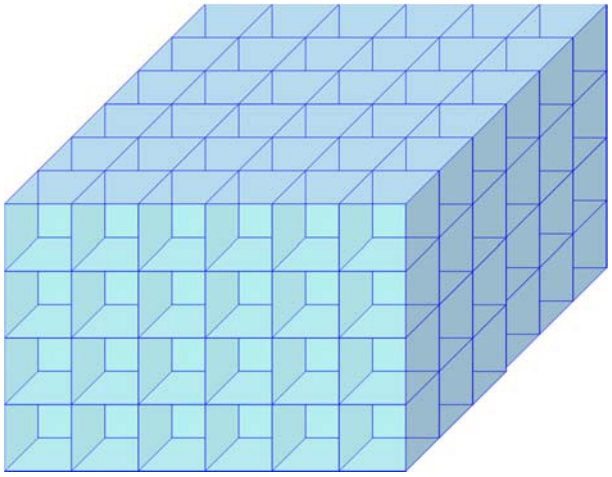
Not to predict the reservoir content

but to anticipate
its dynamic behavior

Upscaling: a challenge for information integration!

Geocellular model definition

A **cellular model** is a schematic description of a reservoir that represents its properties

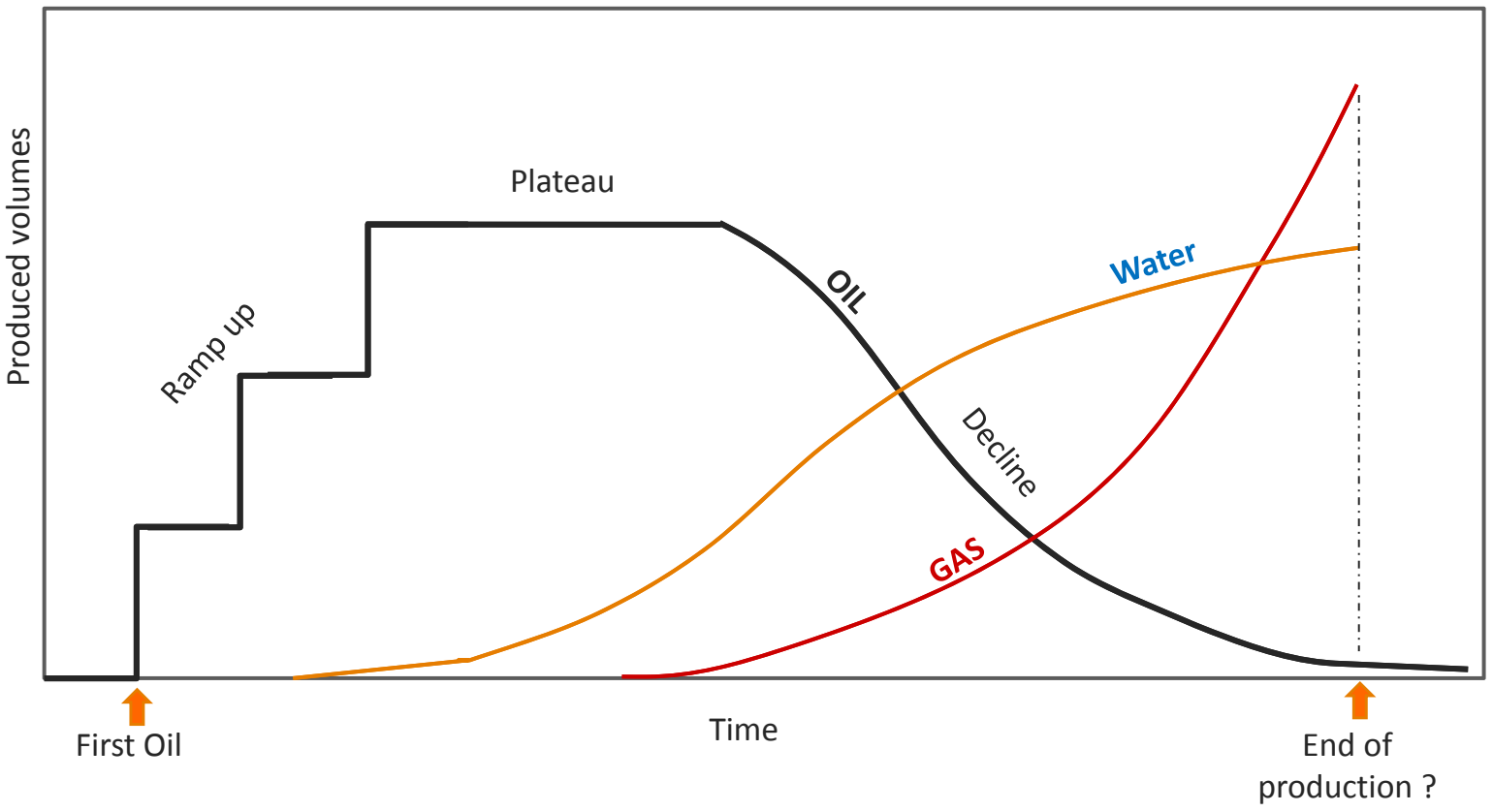


A **cellular model** is required:

- ✓ to understand the **complexity** of reality
- ✓ to **quantify** reality

➔ Modeling objectives: **simplify** to **quantify**

Theoretical production profile of a field



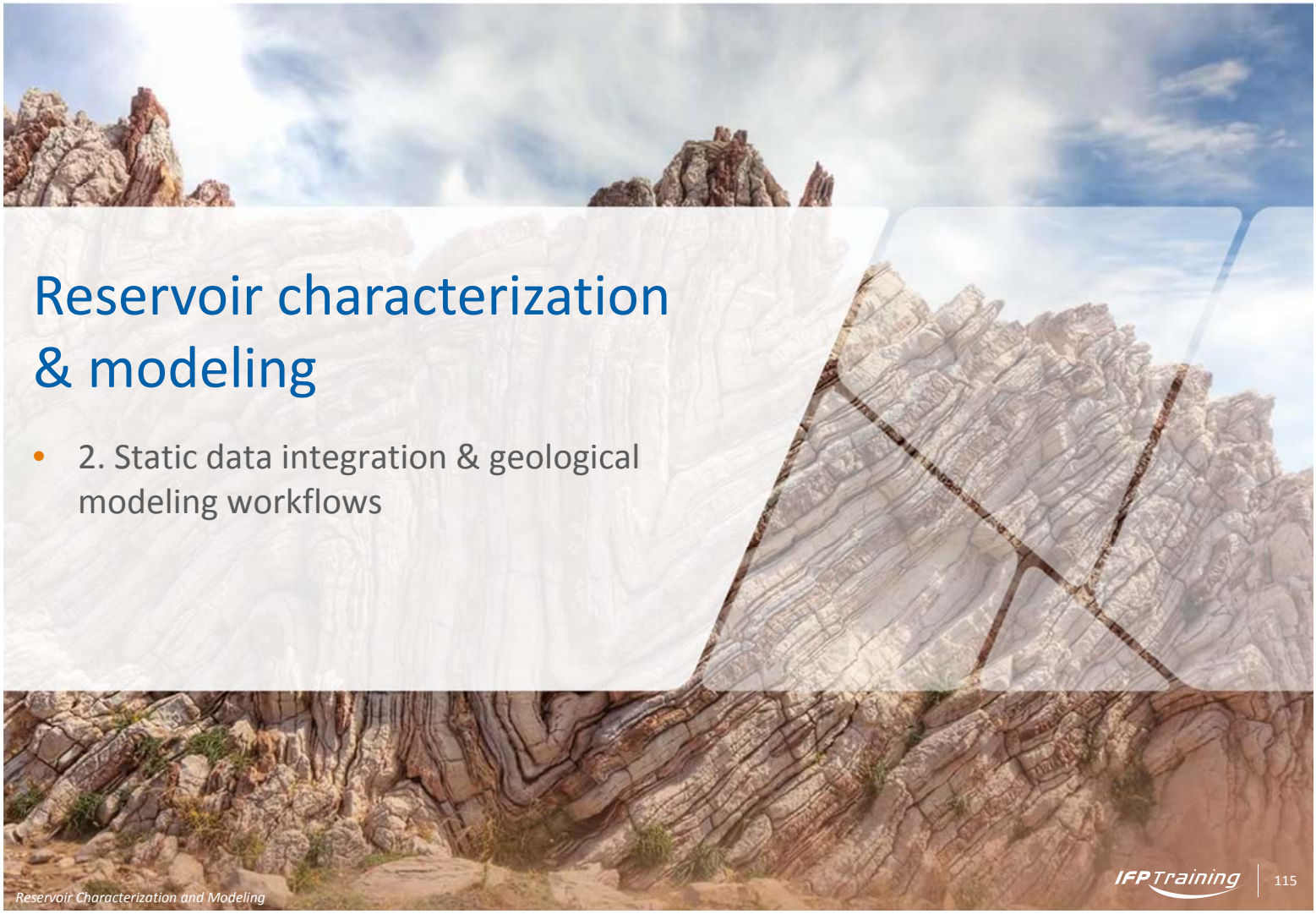
Reservoir modeling objectives

Key points

- **Reservoir model* construction is the main objective of an integrated reservoir study.**
- **This model is used to simulate the field evolution throughout time for:**
  - Well production
  - The fluid displacements (within the reservoir)
  - Pressure evolution
- **The geomodel¤ represents one of the most important phases in an integrated reservoir study workflow, because:**
  - It integrates reservoir geometry and petrophysical properties
  - It takes dynamic information into account
  - It provides key heterogeneity for modeling

* Reservoir model = Dynamic model

¤ Geological model = Geomodel = Geocellular model = Static model



Reservoir characterization & modeling

- 2. Static data integration & geological modeling workflows

The key to success: two steps

Two main steps

Characterization

- To determine **conceptual models** for each discipline topic
- To select **relevant** modeling **parameters**
- To choose a modeling sequence (according to the available data)

Modeling

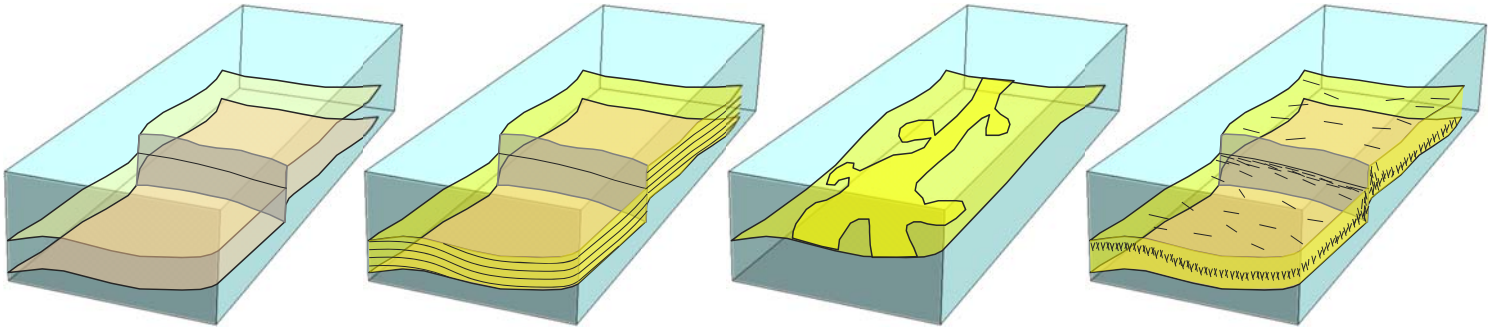
Use the parameters resulting from characterization to build a **numerical** (digital, computed) **model**

Notion of conceptual model

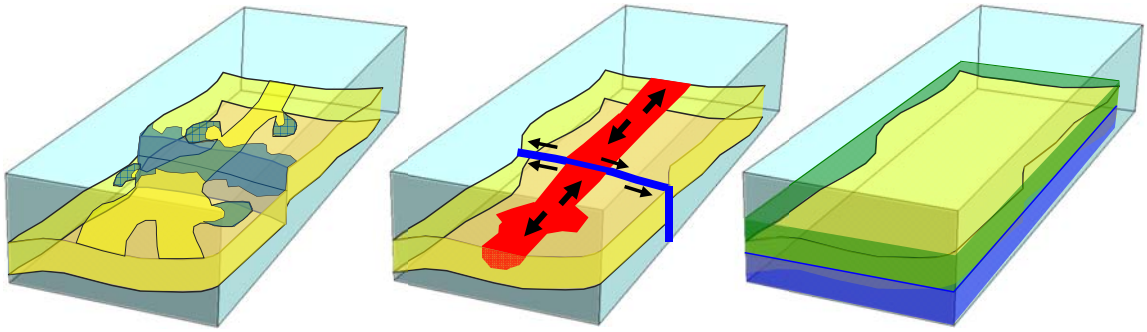
- All geoscientific techniques can help to build conceptual models
- Conceptual models help integrated team members to reach a global understanding of studied reservoir
- Each **preliminary model** is related to parameters that will be used **to populate the final numerical** model
- To make a conceptual model for each discipline topic, i.e.
- To prepare a table of uncertainties, at each step for each topic

→ **Time for modeling will be reduced**

Conceptual models workflow

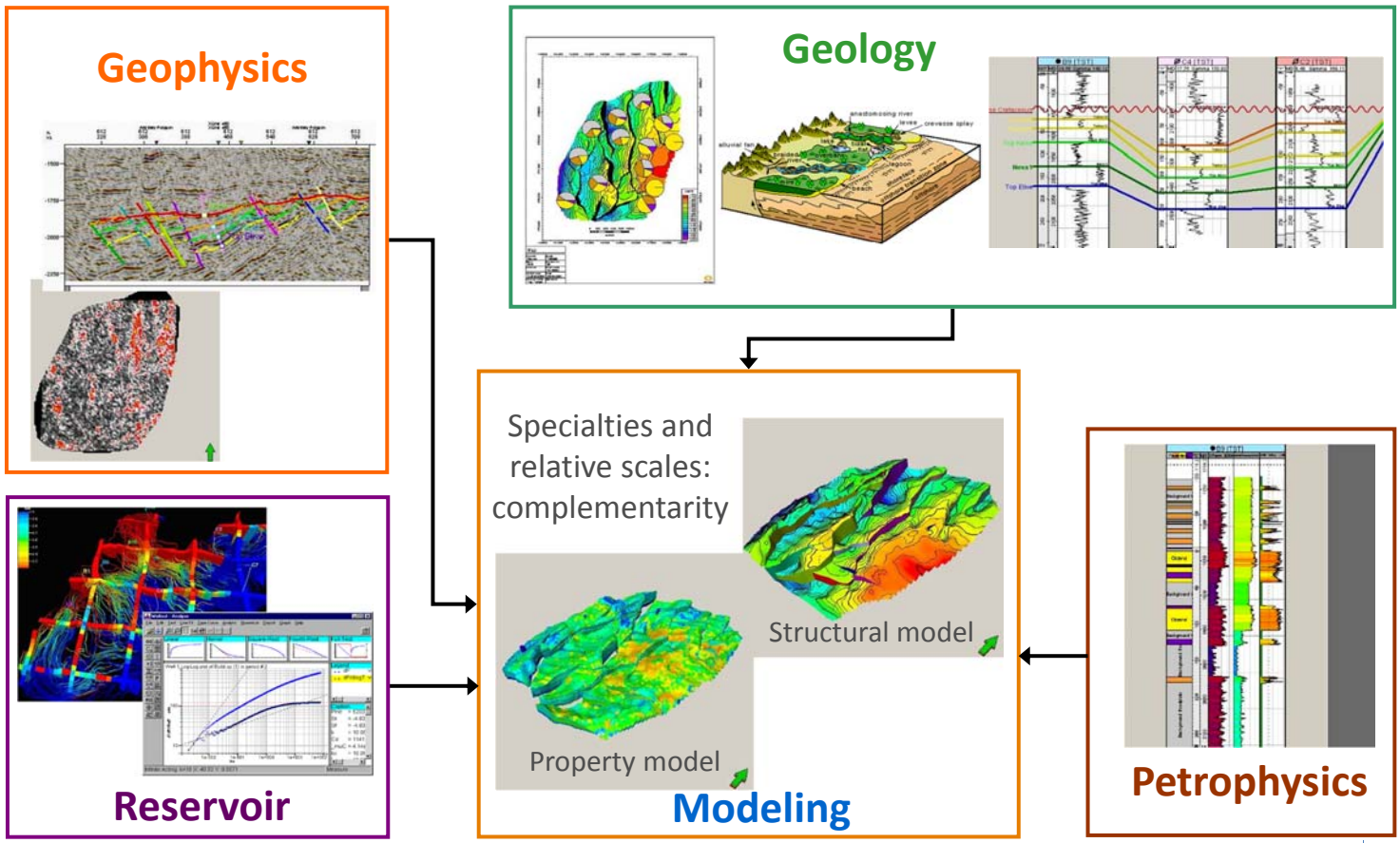


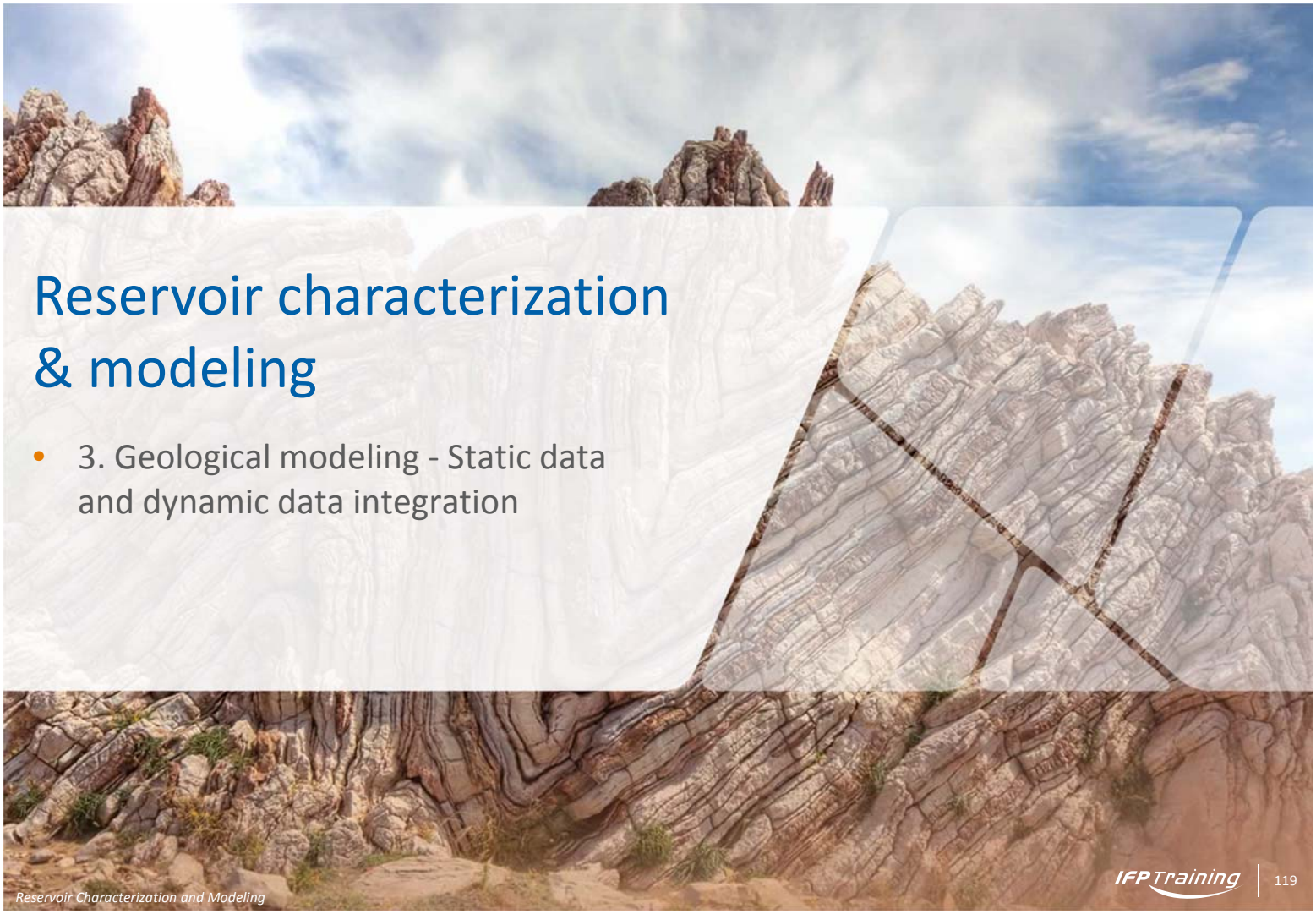
Structural model | Stratigraphic model | Sedimentological model | Fracture model



Diagenesis model | Heterogeneity model (fluid flow) | Fluid model

Reservoir modeling = Integration!





Reservoir characterization & modeling

- 3. Geological modeling - Static data and dynamic data integration

3. Geological modeling

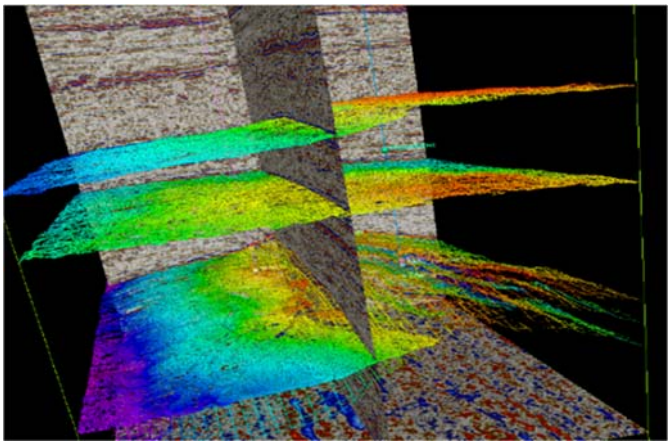
Static data and dynamic data integration

- **Seismic data**
- **Well data**
  - Reservoir parameters
    - Porosity: log and core
    - Permeability: log, core and well test
    - Saturation and contacts: log and core
    - Facies
      - genetic (i.e. geology-oriented: lithofacies from cores)
      - rock types (i.e. petrophysics-oriented: petrofacies from SCAL)
    - Production history

Reserves = GRV * NTG * PHIE * Shc * FVF * RF

Objectives and deliverables

- **Seismic what for?**
  - Structural and facies information between wells (reservoir framework: top and base surfaces) is extracted from seismic data

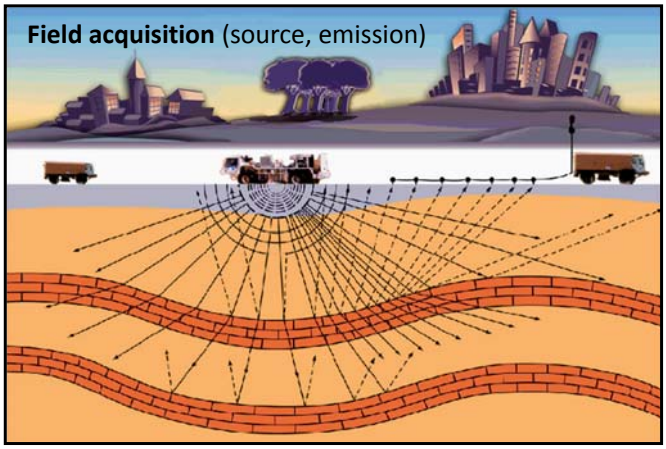


- **Seismic for reservoir architecture**
  - Structural maps and grids
  - Attributes maps and grids
  - Fault network, map and grids
- **Seismic for reservoir information: seismic data can be linked with the following parameters**
  - Fractures
  - Lithology/Sedimentological facies
  - Porosity

➔ **Deliverables are maps and grids**

2D land reflection seismic principle

- **Field set-up and geometry:**
  - Sources (land and marine)
  - Receivers (geophones, hydrophones)
  - Recording lab (truck, vessel)

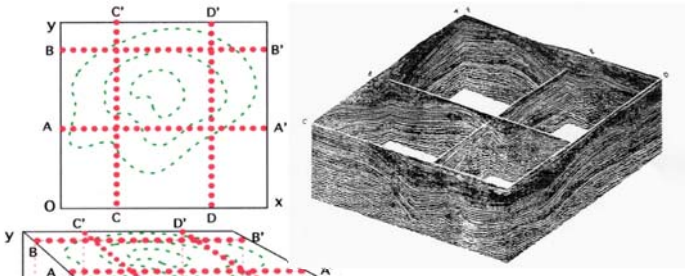


- **Geophysics is applied at each step of exploration**
  - General exploration (screening)
  - Detailed exploration (prospect-focused)
  - "Wildcat" exploration well positioning
  - Delineation well positioning (appraisal)
- **Geophysics is also used in production**
  - Development well positioning
  - Reservoir monitoring (4D seismic)
- **Geophysics is even used in drilling**
  - Well path monitoring (geosteering)

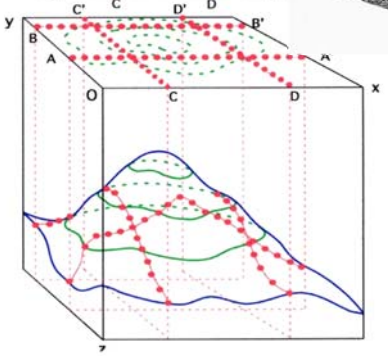
2D versus 3D seismic acquisition

- **Wide, variable spacing between profiles**
- **Blind zones in acquisition coverage**
  - Significant related uncertainty

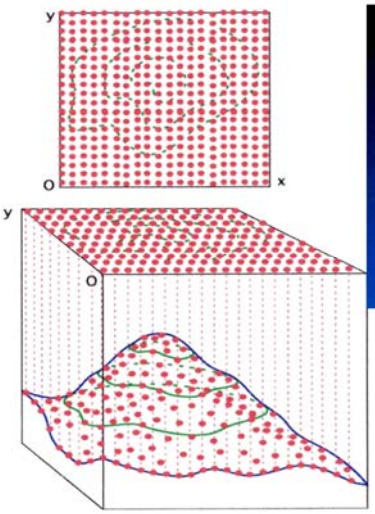
- **Homogeneous coverage of area**
- **High density data sampling**
  - Reduced blind zones
  - Enhanced signal quality and processing
- **Reduced related uncertainty and risks**

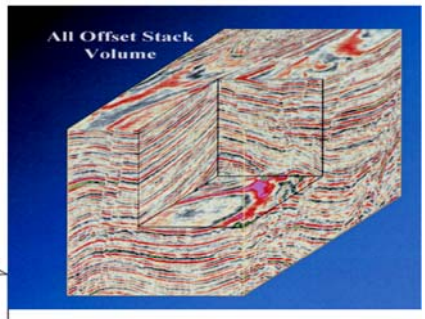


2D seismic mesh



2D seismic surface sampling
→ Poor lateral resolution



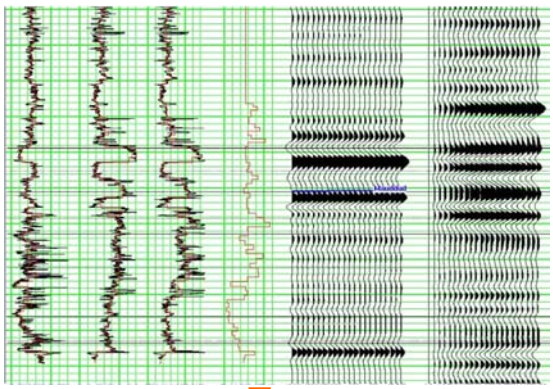


3D seismic block

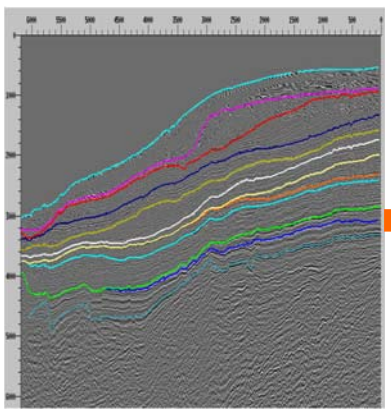
3D seismic surface sampling
→ Better lateral resolution

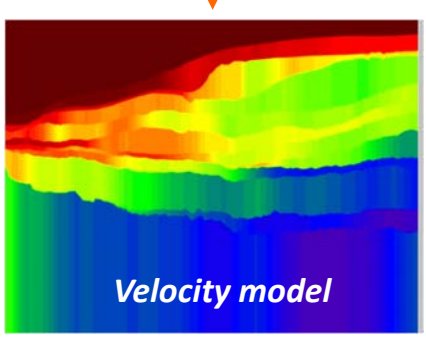
Time-to-depth conversion

Well logs Synthetic seismogram

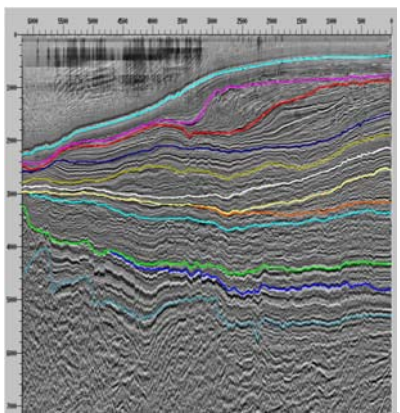


Time



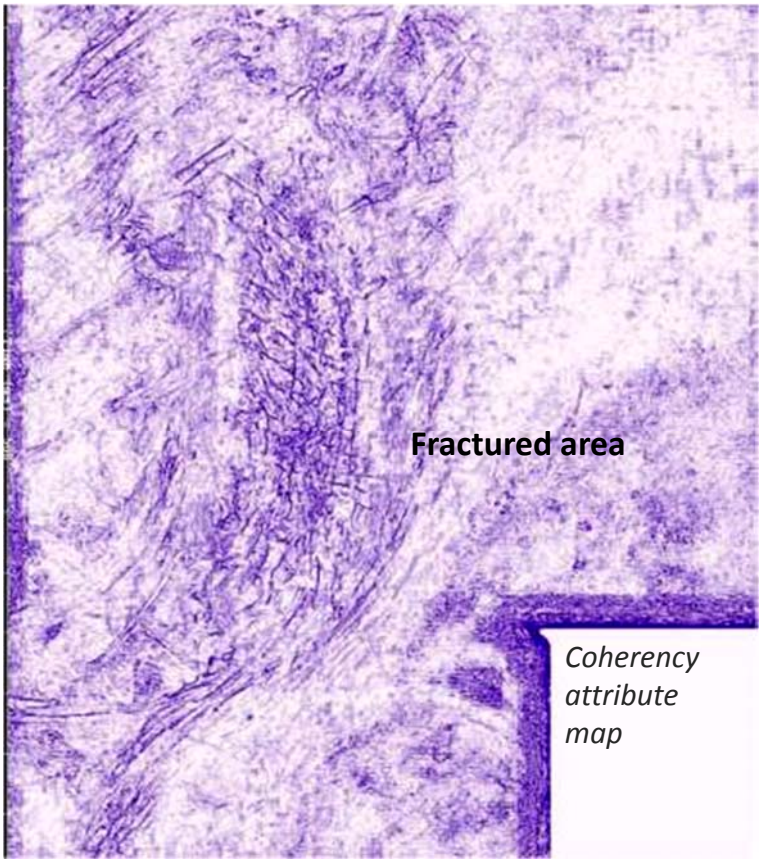


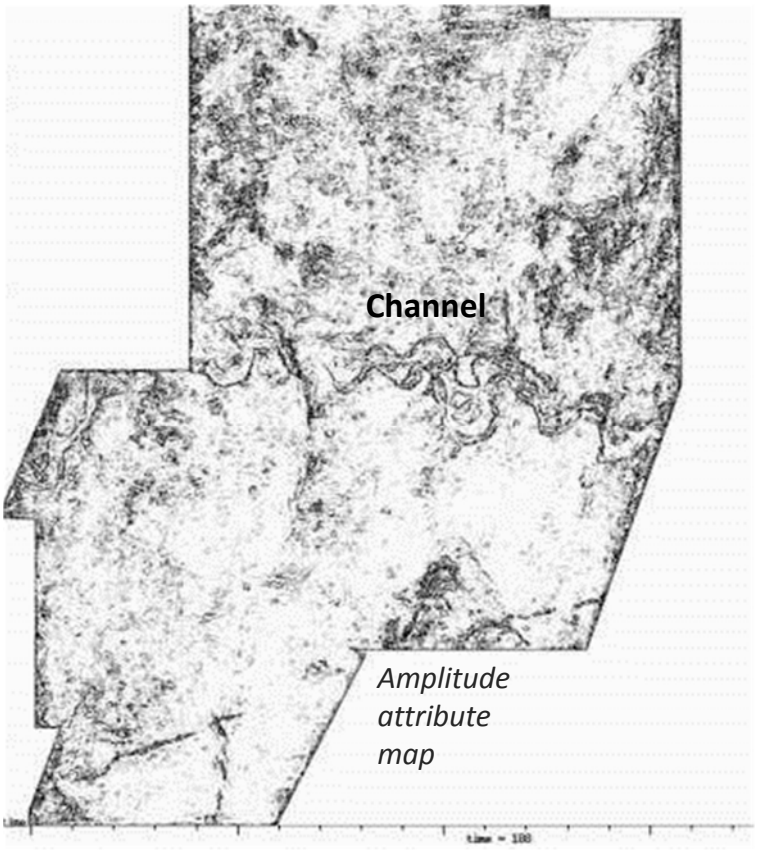
Depth



Get information about subsurface

Fractures - Sedimentary bodies

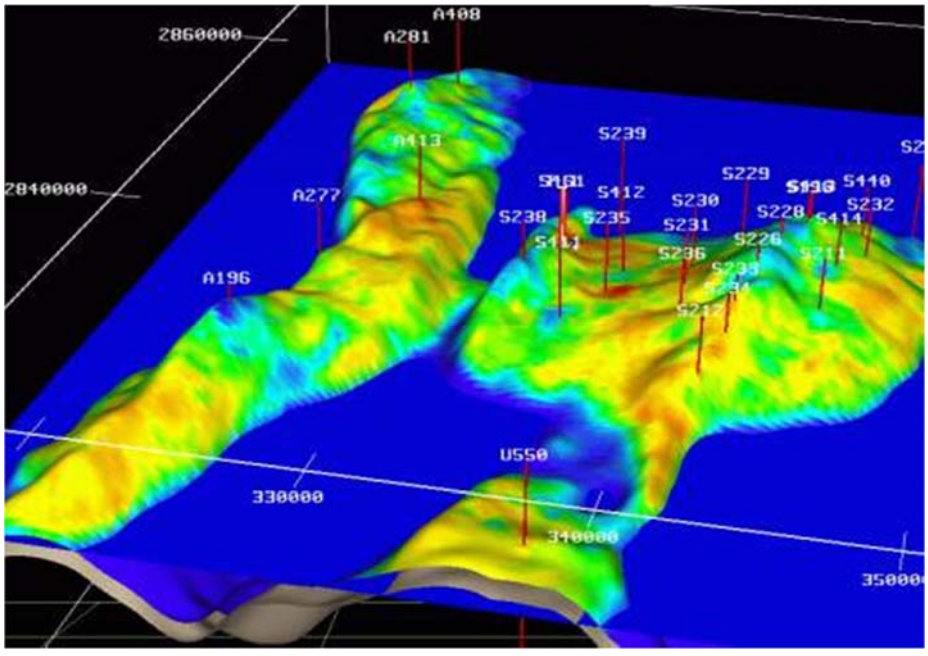




Get information about subsurface

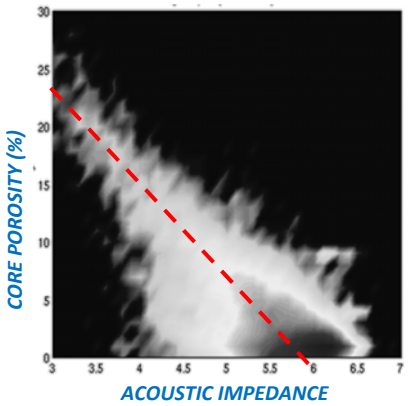
Porosity from attributes

Acoustic impedance vs porosity in carbonate reservoir

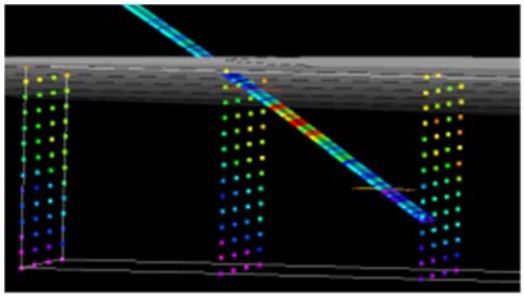


3D geostatistical distribution of reservoir porosity

→ Optimized positioning of future development wells



Seismic calibration with core information



Predicted porosity distribution along planned well path

Key points

- **Seismic provides an image of the subsurface (geometry) that is used** (along with other data) **to identify possible hydrocarbons accumulations (structures)**
- **Seismic data interpretation results are used to build models** (both geological and reservoir) **that summarize what can be understood at a given time (Porosity and permeability distribution)**
- **Seismic models are validated (geologically) only by drilling** (sampling "ground truth")
- **Data gathering during development drilling, together with seismic information, allow models** (both static and/or dynamic) **to evolve**
- **4D seismic allows to monitor the evolution of a producing field** (water injection, sweep efficiency,…) **by comparing seismic images taken over time**

Wireline logging

- **Recording of the physical phenomena linked with the petrophysical characteristics of the drilled formations and fluids in place.**
- **Recording after the drilling phase, every 15 cm down to 3 cm (1 foot > 1 inch)**
- **The logs provide a continuous image of the subsurface (in situ) detailed information but limited to the wellbore neighborhood (< 1 m diameter around the hole)**
- **Three types of logs:**
  - Well logs for geologists: formation & fluid evaluation and characterization & quantification
  - Well logs for drillers: technical information (e.g. cementation quality, sticking point detection for fishing)
  - Well logs for production engineers: to analyze all phenomena linked to the fluids and their displacement

Main logging tools

	Measured phenomena (borehole, formation or fluid)	Depth of investigation	Vertical resolution	Application
Caliper	**Well-bore diameter**	none	1,3 cm	Identification of **mud cake**, i.e. presence of a **reservoir**
GR	**Natural radioactivity**	30 cm	30 cm	Identification of **shaly formations** (seals)
Resistivity	**Resistivity and conductivity of formations (rocks & fluids)**	3 cm to 2 m	10 cm to 1 m	Identification of **fluid types** Measurement of **hydrocarbon saturation** and **contacts**
Neutron **Density** **Sonic**	▪ **Emission of neutrons** ▪ **Emission of gamma rays** ▪ **Travel time of acoustic waves**	12 to 25 cm ~10 cm 1 to 12 cm	40 to 60 cm 10 cm 60 cm	Formation's **lithology** Reservoir's **porosity**

Well data: scales of observation

Thin section

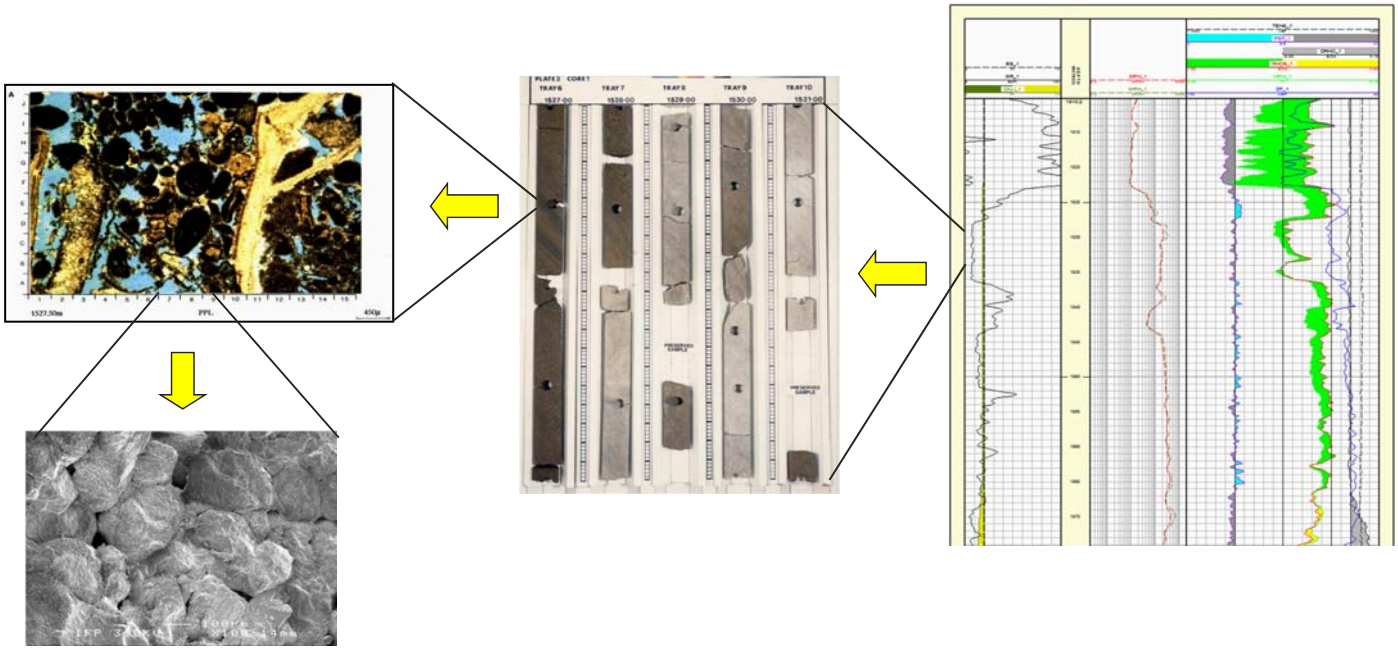
µicron → mm

Core

mm → dm

Log

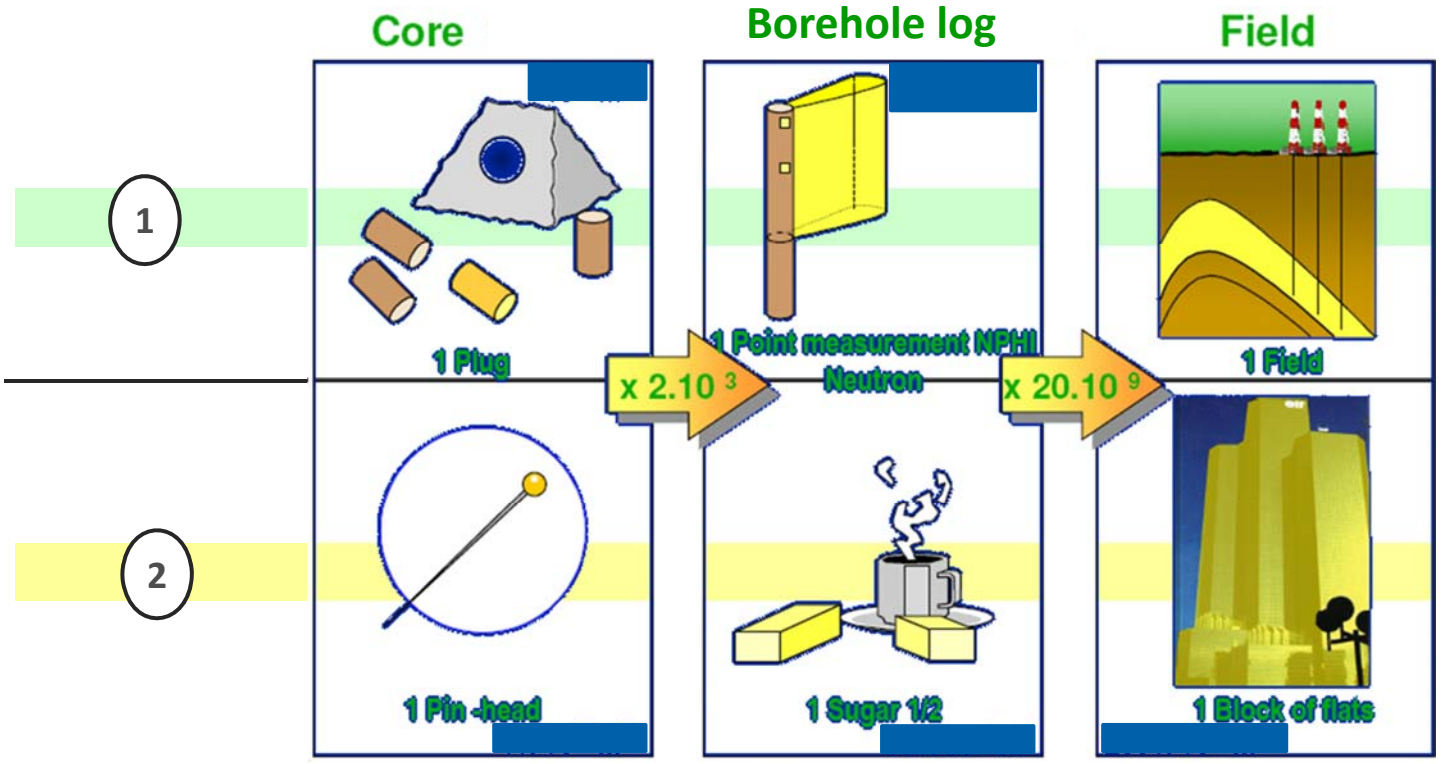
dm → m



Scanning Electron Microscope

µicron

Scale ratio of data sets

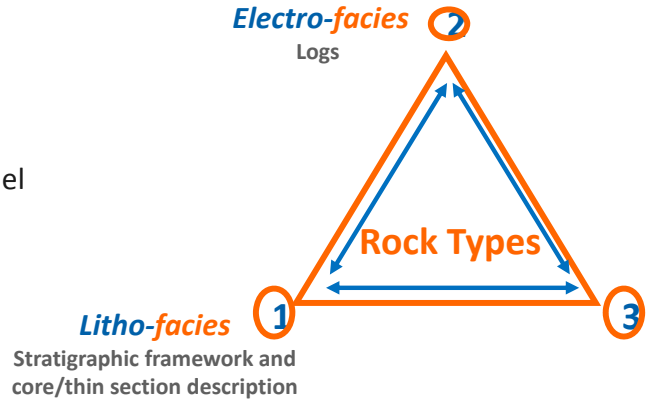


Scale ratio (1) = **Scale ratio (2)**

Rock type definition

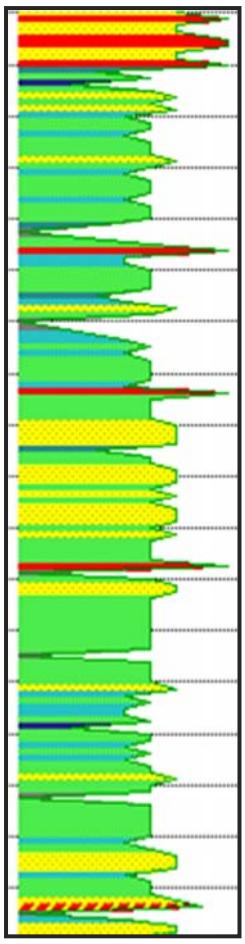
Facies integration

- **Rock type = homogeneous response in terms of Phi/K**
  - → **Preliminary flow unit determination** (preparing dynamic model)
- **Homogeneous fluid flow properties**
  - Capillary pressure curves
  - Relative permeabilities
  - Introduced in reservoir simulation model



- **Electrofacies interpretation** with **PHI/K** plots (core data), **electrofacies** gathering and connection **with capillary pressure (Pc) curves**
- **Electrofacies analysis** using **[Phi/K]-related logs** (or interpreted logs)

Rock typing: integration of all facies

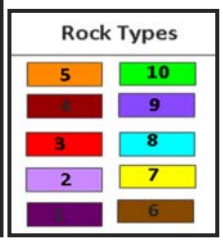


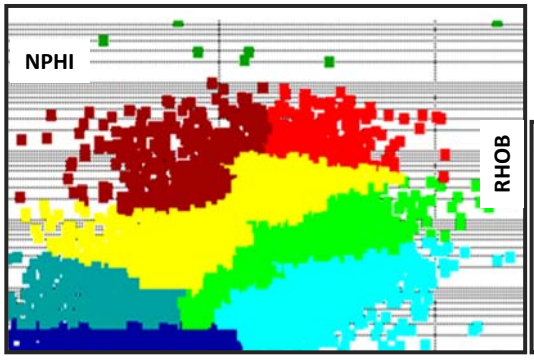
- **Litho-facies**: sedimentological facies and petrology
- **Electro-facies**: well log analysis
- **Petro-facies**: core analysis and petrophysical measurements

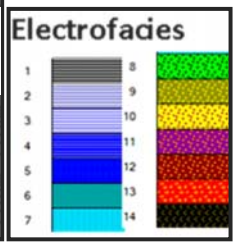
→ **Rock types are determined:**

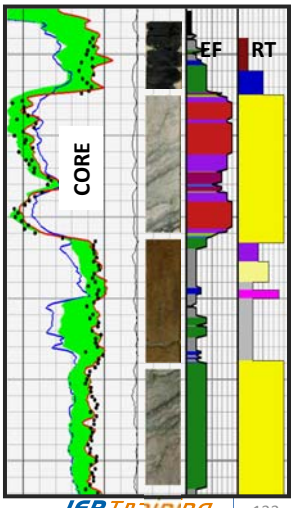
- in a specific geological context
- with a specific log suite
- for both cored and non-cored intervals

  RT should integrate **capillary pressure** data

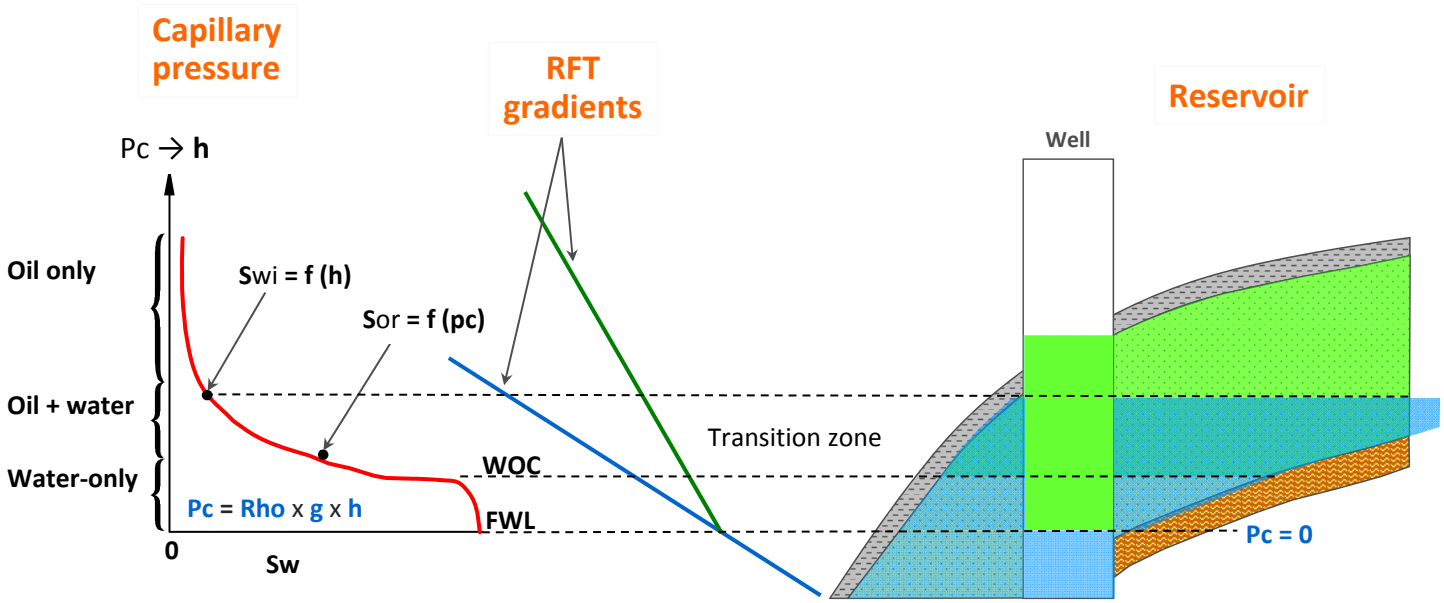








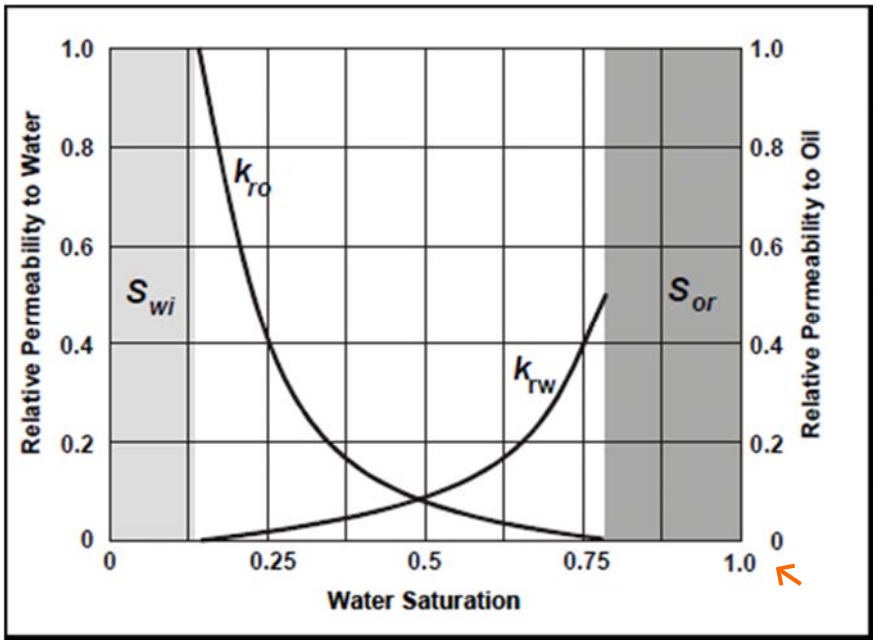
Capillary pressure and fluid contact summary



FWL = Free Water Level → Pc = 0

WOC = Water-Oil Contact → Displacement pressure (Pc*d*)

K_r – Example Oil/Water



a: only oil is moving: Kro=1 and Krw=0

b: Sw ↗: oil flows less easily

c: Kro = Krw and Kro + Krw < 1

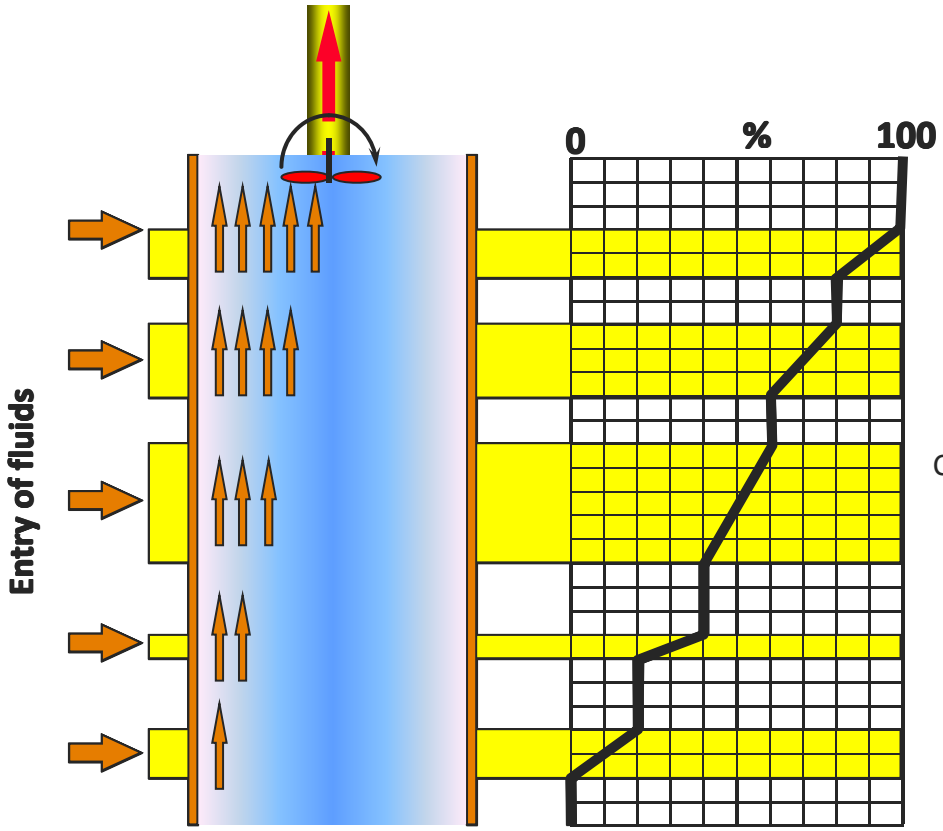
K *2 phases* < K *1 phase*

d: oil is not mobile any more (So=Sor), Krw(Sor) < 1

The two curves represent **oil and water flows in the reservoir.**

Except for end points,
The sum of relative permeabilities is always strictly lower than 1

Continuous flowmeter (PLT)



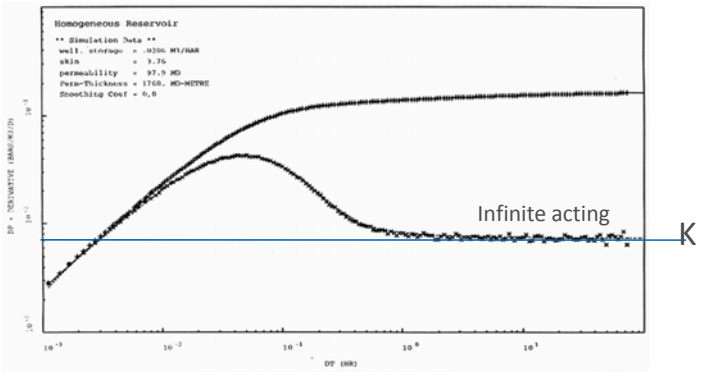


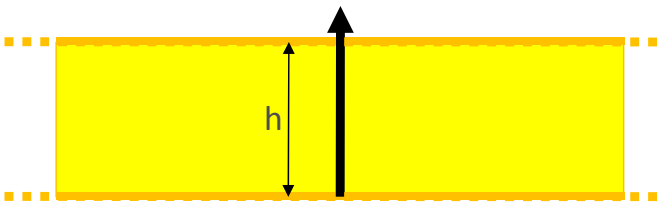
Cumulated contributions of each interval to total fluid production

Information from propeller speed measurement is converted to production (speed is proportional to flow)

Well test and reservoir characterization

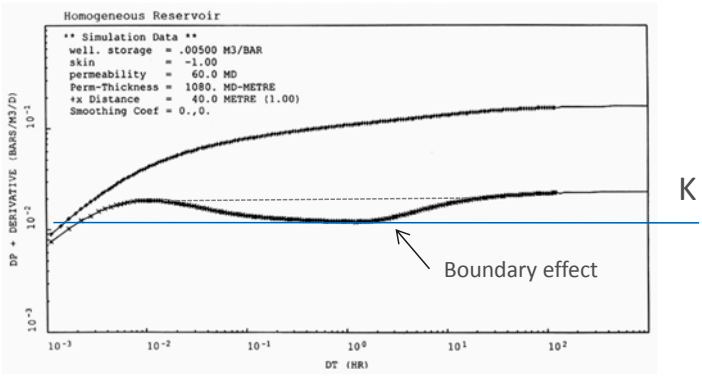
Homogeneous reservoir

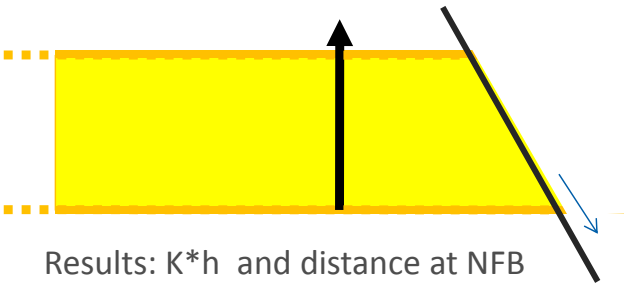




Results: K*h

Homogeneous with one no-flow boundary reservoir



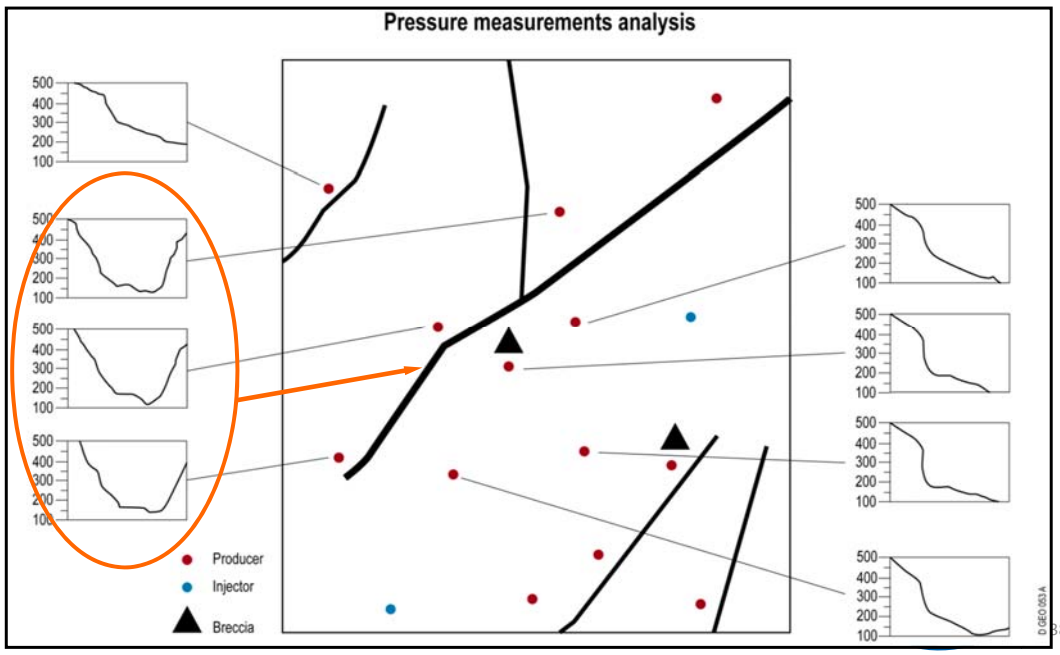


Results: K*h and distance at NFB

Pressure measurements and production history

- **Identification dynamic barriers with pressure data**
  - Different pressure behavior between 2 groups of wells define a permeability barrier that can be correlated with the presence of a conductive fault
  - Note: GOR and water break-through data can also be used to determine preferential trends of hydraulic flow

P° increase due to water injection conducted by fault



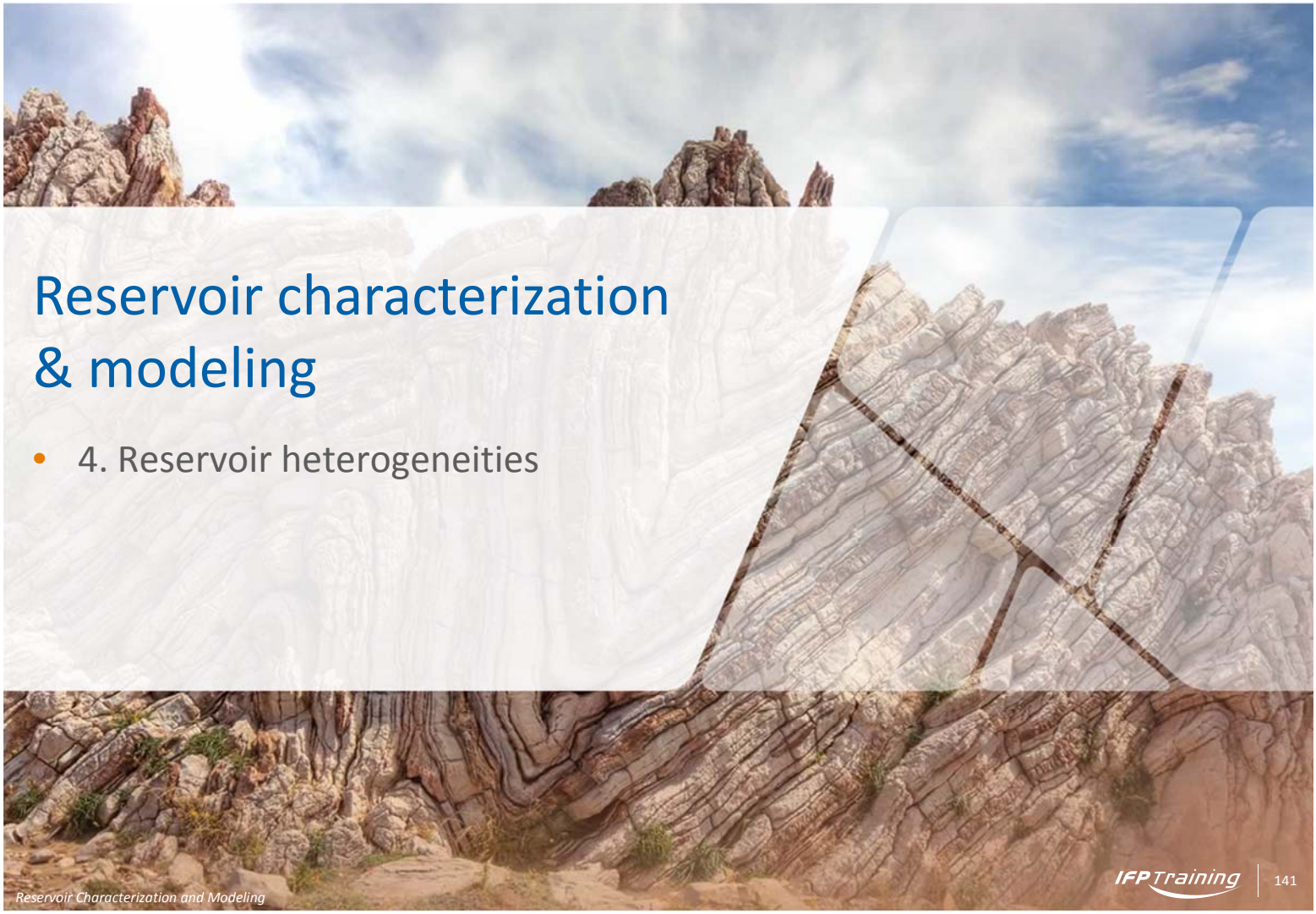
Breccia = fractures on cores

Dynamic data integration

Key points

- **An integrated team for a reservoir study has a common objective: i.e. to build a conceptual model**
- **This model should integrate both sedimentological and structural elements in order to explain reservoir anisotropy regarding fluid flow. This includes all data from seismic and wells (logs and cores)**
- **Dynamic characterization is required to detect anomalies which impact fluid flow**
- **Identified anomalies are critical and must be incorporated into both:**
  - The geological model
  - The reservoir model

Notes



Reservoir characterization & modeling

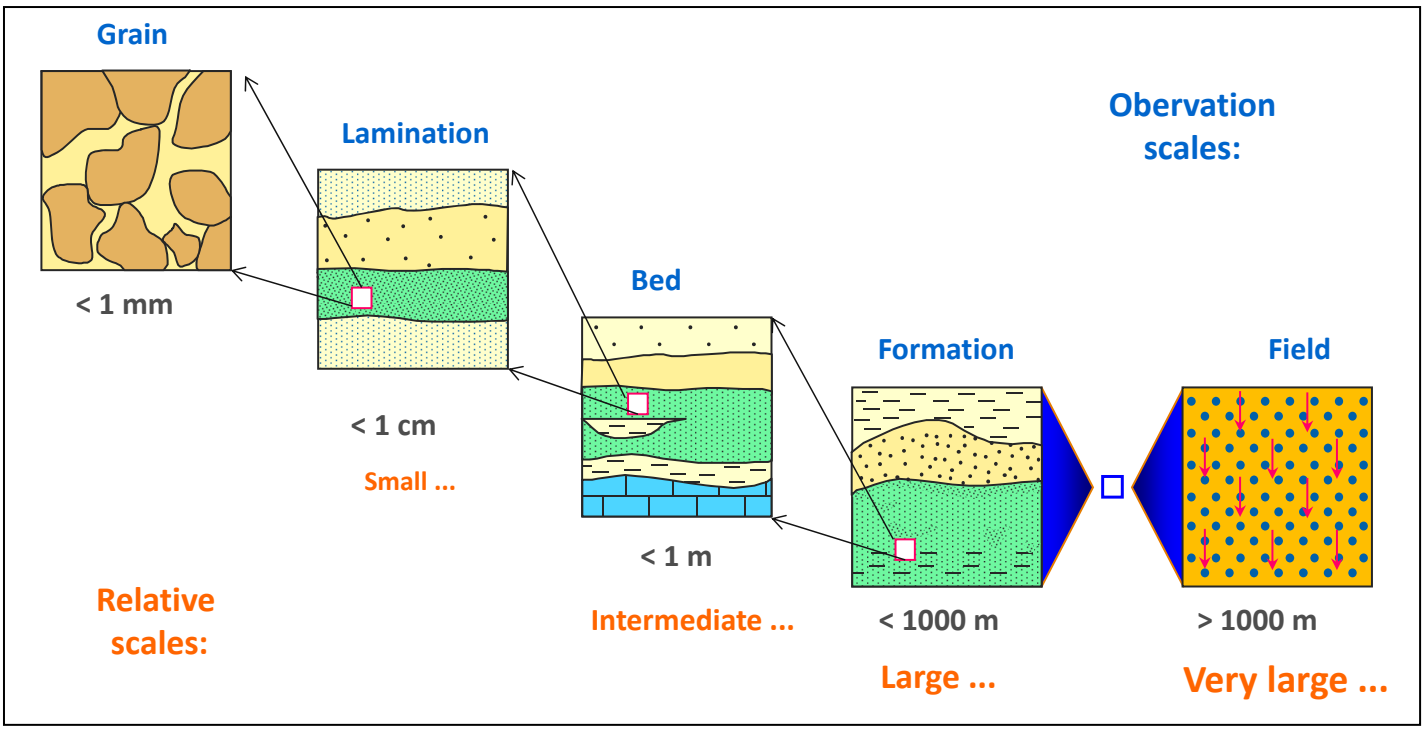
- 4. Reservoir heterogeneities

Reservoir heterogeneity: concepts

- **Basic principle**
  - Identify the smallest element that might impact production
- **To build a consistent and relevant model:**
  - All the variations in the reservoir quality must be analyzed and classified in a manner that the main heterogeneities are clearly highlighted
  - For a given study, all heterogeneities that can affect fluid flow are considered as key heterogeneities

Reservoir heterogeneities characterization calls for the cooperation between all professionals involved in the study (i.e. from geophysicists to reservoir engineers)

Scale of reservoir heterogeneities

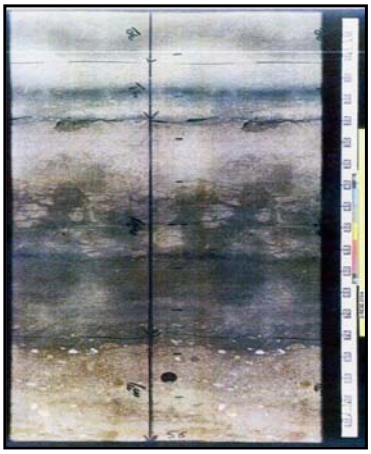


(from Krause and Collins, 1984)

Heterogeneities and investigation tools

do not always have the same scale…

Reservoir heterogeneities



Sandstone with shale baffles



Intense network of small impregnated fractures (carbonate)



Stylolites (carbonates)

K↓

Dissolution in karst (super K)



K↑

Key points

- **To build a consistent and relevant model for an integrated study:**
  - All reservoir heterogeneities must be identified and classified (main ones highlighted)
  - All the heterogeneities that can impact the fluid flow are considered as major heterogeneities
  - Even the smallest elements that can affect production need to be identified and modeled
  - The geological model must take all significant heterogeneities into account
  - Characterization of reservoir heterogeneities calls for integrated multi-disciplinary approach (cooperation and team work)

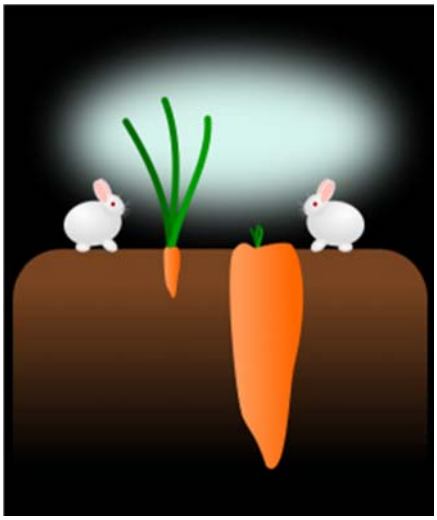
Reservoir characterization & modeling

- 5. Reservoir uncertainties

Uncertainties are to be considered

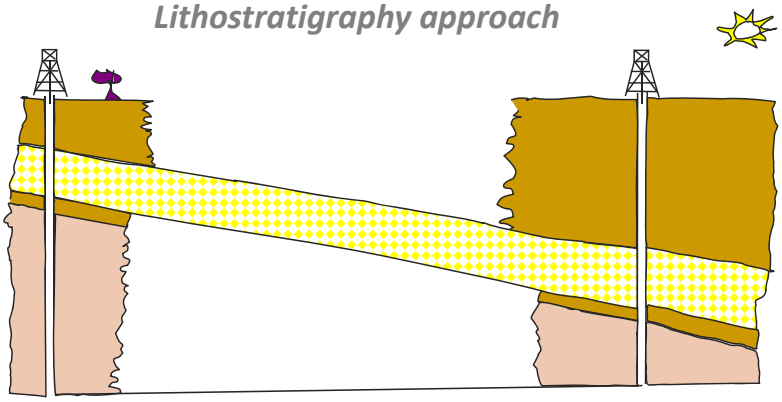
- **Uncertainties are everywhere!**
  - Lack of data
  - Complex physics
- **Not taken into account uncertainties can ruin a project**
  - Unexpected events…

→ Should be defined by the team in charge of the project with the help of specialists



Uncertainties in sedimentological interpretation

Lithostratigraphy approach

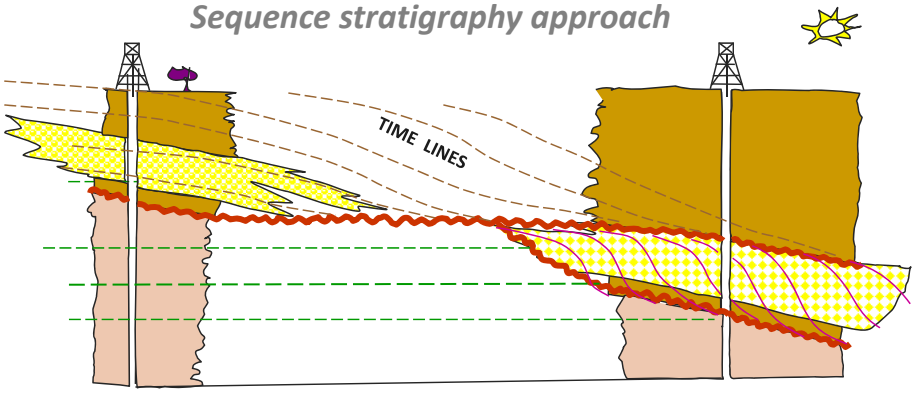


Offshore

Shoreface
Offshore
Coastal plain

Good facies analysis but wrong sedimentological model: beware of correlations!

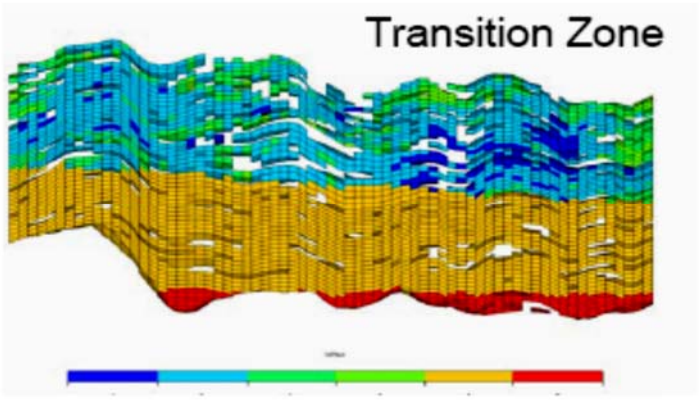
Sequence stratigraphy approach

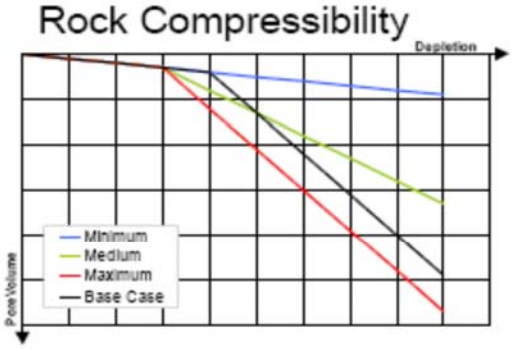


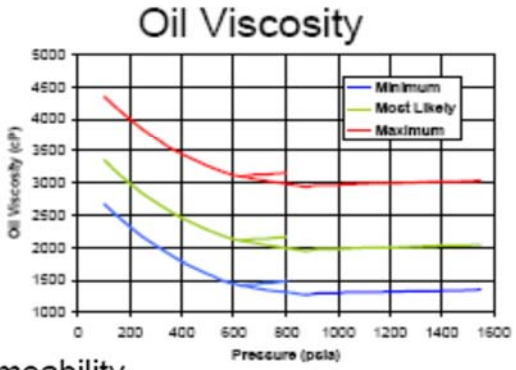
Offshore

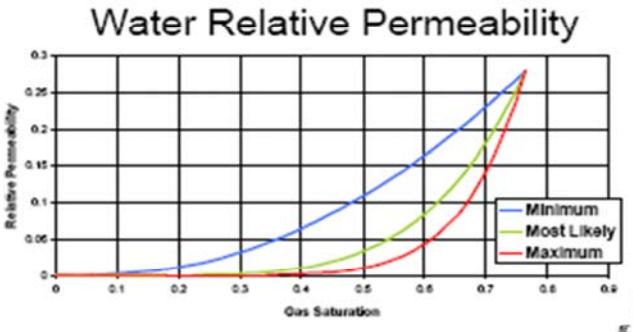
Shoreface
Offshore
Coastal plain

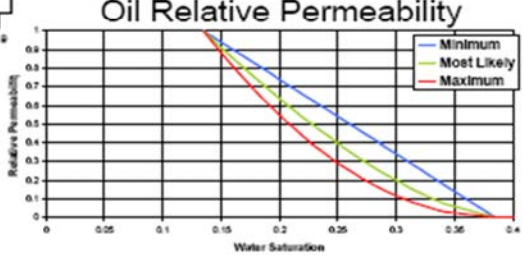
Uncertainty in dynamic modeling











Key points

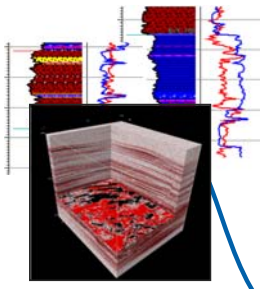
- **To build a consistent and relevant model for an integrated study:**
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  - Even the smallest elements that can affect production need to be identified and modeled
  - The geological model must take all the significant heterogeneities into account
  - Characterization of reservoir heterogeneities calls for integrated multi-disciplinary approach (cooperation and team work)

Notes

Reservoir characterization & modeling

- 6. Reservoir modeling

Data integration in reservoir modeling

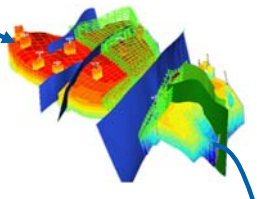


Well and seismic data

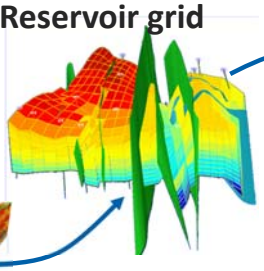
structural model



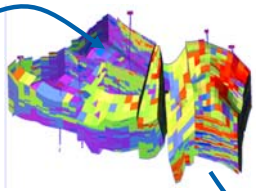
Stratigraphic model

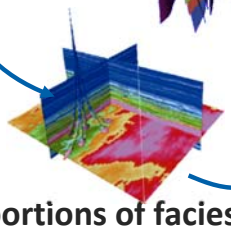


Reservoir grid

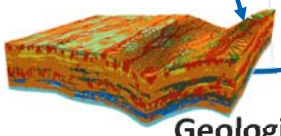


Upscaling



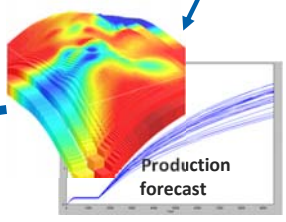


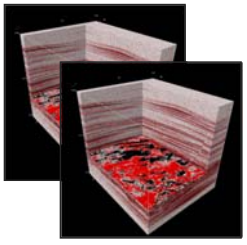
proportions of facies



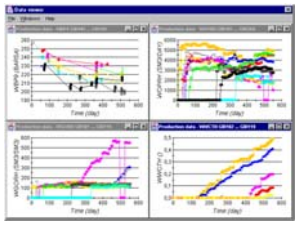
Geological model : Facies, porosity, permeability

Flow simulation





Integration of 4D seismic data



Integration of production data



Reserves and resources classification

Reserves and resources classification

Outlines

1. **Introduction**
2. **Reserves definitions**
   1. SPE Petroleum Resources Management System (PRMS)
   2. Security and Exchange Commission (SEC): some rules
3. **Practical guidelines**
4. **Reserve and production profile forecast**



Reserves and resources classification

1. Introduction

Definitions

What are the reserves?

- **Does the word RESERVES mean only HIIP x Recovery Factor?**
- **RESERVES are: the EVALUATION of HYDROCARBONS that are anticipated to be COMMERCIALLY RECOVERABLE from a given date forward from KNOWN RESERVOIRS by SPECIFIED TECHNIQUES (Project FDP) and at SPECIFIED ECONOMIC conditions**
- **Key concepts:**
  - Commercially recoverable
  - Known reservoirs (excludes exploration) (2G&R)
  - Reserves (i.e. remaining to produce) vs Ultimate Reserves (i.e. already produced + reserves)
  - Specified techniques (development, production, drilling)
  - Specified economic conditions (fiscal terms, ..)
  - Contracts (planning & all)

Definitions

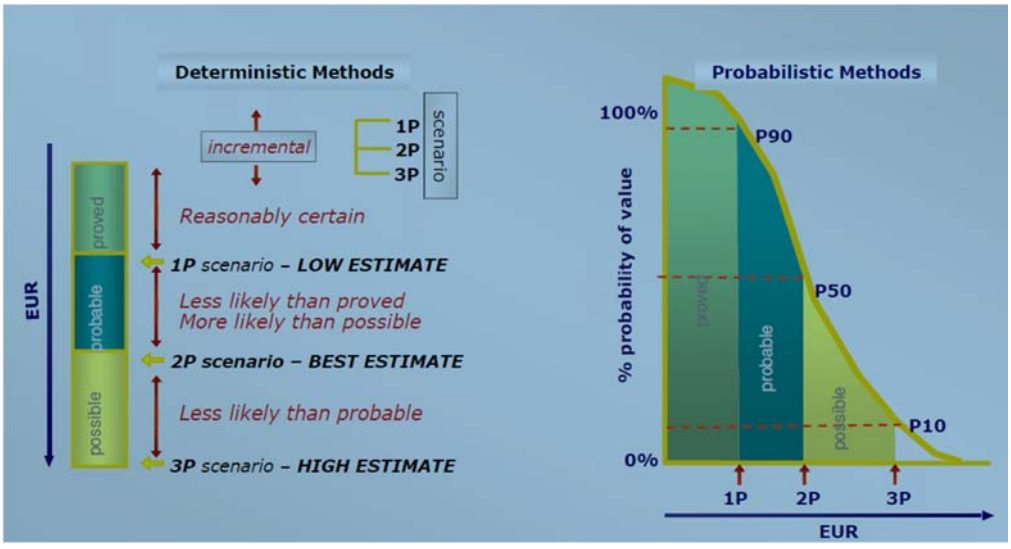
HCIP & Reserves

- **The total estimated amount of oil /gas in a reservoir, is called oil / gas in place:**
  - OOIP / IGIP widely used in Petroleum industry
  - OIIP / GIIP
  - STOIIP / STIGIP
  - ….
- **The producible fraction is considered to be reserves (with economics & project)**
- **The ratio of oil / gas reserves to total oil / gas in place is the recovery factor**
- **Recovery factors vary largely (particularly among oil fields)**
- **The recovery factor of any particular field may change over time**
  - With additional phases of development (infill wells in poorly swept area, upgrades of subsurface & facilities)
  - With the implementation of new recovery mechanism & techniques (EOR/IOR)
  - Due to changes in economics (CAPEX, OPEX, sales prices,..)
  - Contractual conditions (terms of contracts, license extension …)

Definitions

HCIP estimation methods

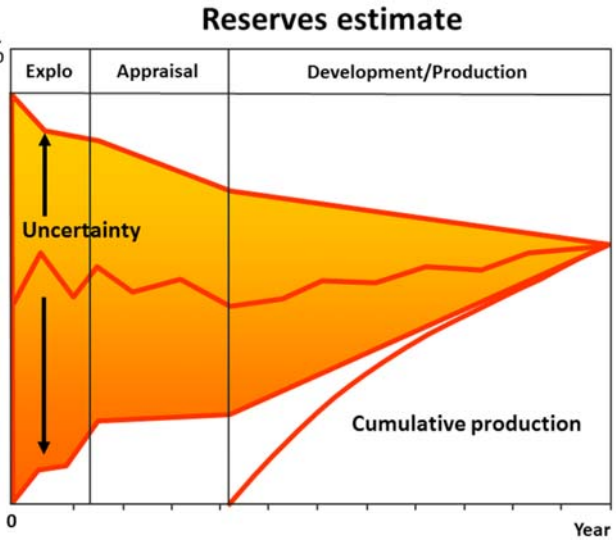
- **The method of estimate of the resources is called probabilistic when the full range of known geosciences, engineering, and economic data are used to generate a continuous range of estimates and their associated probabilities.**
- **The method of estimate of the resources is called deterministic when a single value on known geoscience, engineering, and economic data is used to generate a discrete estimate.**



Definitions

Reserves

- **PROVED RESERVES (1P)**
  - Minimum expected reserves
  - Having a cumulative probability of 90 % (P90) or 95 % (P95)
  - Actual economic and technical conditions (resulting from an actual commercial development plan)
    Subdivided into :
    - proved developed
    - proved undeveloped : awaiting investment



- **PROVED + PROBABLE RESERVES (2P)**
  - Reasonably expectable reserves
  - Having a cumulative probability of 50 %
  - Developable under actual economic and technical conditions
- **PROVED, PROBABLE & POSSIBLE RESERVES (3P)**
  - Maximum possible reserves under the most favorable conditions
  - Having a cumulative probability of 5% (P5) or 10 % (P10)

Development Plans are designed on the 2P reserves

Risk is evaluated with the economy of the 1P reserves case

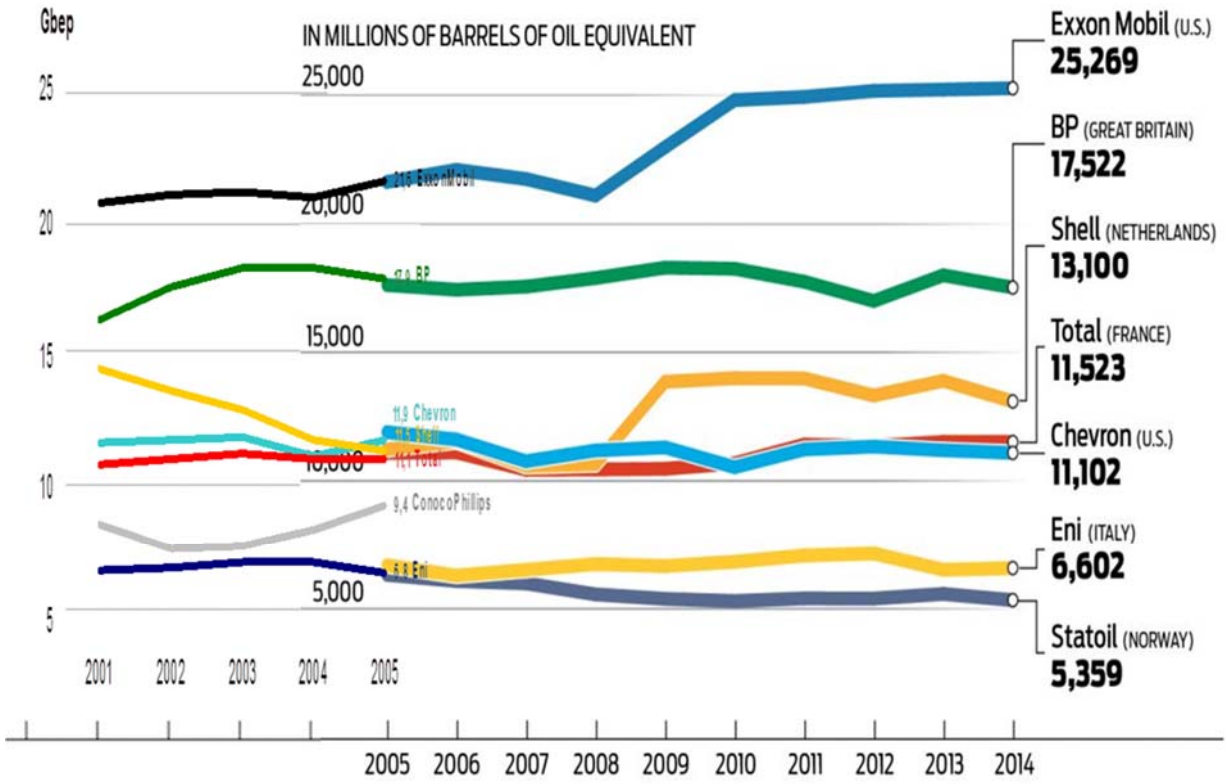
Reserves & booking

- **Reserves & resources are a crucial part of the O&G industry - IOC:**
  - Fundamental part of the oil business
  - Internal basis (Operated and non operated) for O&G companies in their processes: decision, economics & finances
  - Major impact on any listed O&G company's results:
    - Confidence from our shareholders and
    - From the market in terms of professionalism and integrity of the company
    - Company's value in term of assets
- **Annual consolidations done with rigor (consistent with the industry standards and the certification organisms) as evaluations may be subject to audits (partners, different entities for companies in Stock Exchange)**


Discovery Well #7 to the left. Dhahran - 1939 ~ TCB

Reserves booking …

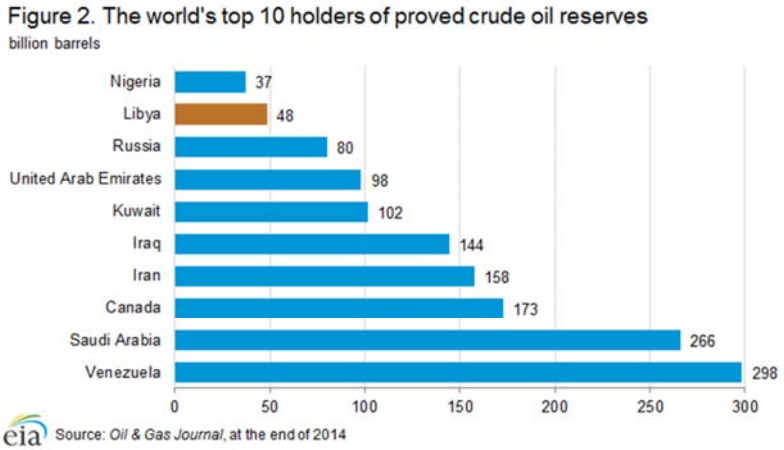
IOC Reserve

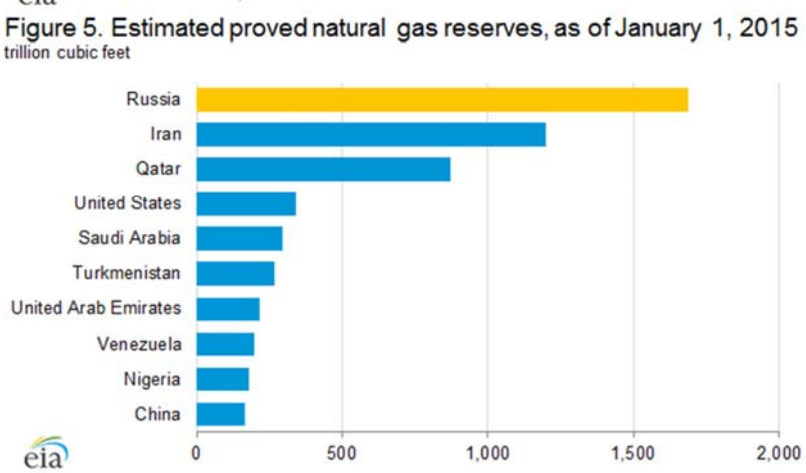


Sources: Bloomberg, Securities and Exchange Commission

Reserves booking …

NOC Reserve





Reserves and resources classification

2. Reserves definitions

What is the oil reserve?

- **Why is a reserve definition needed?**



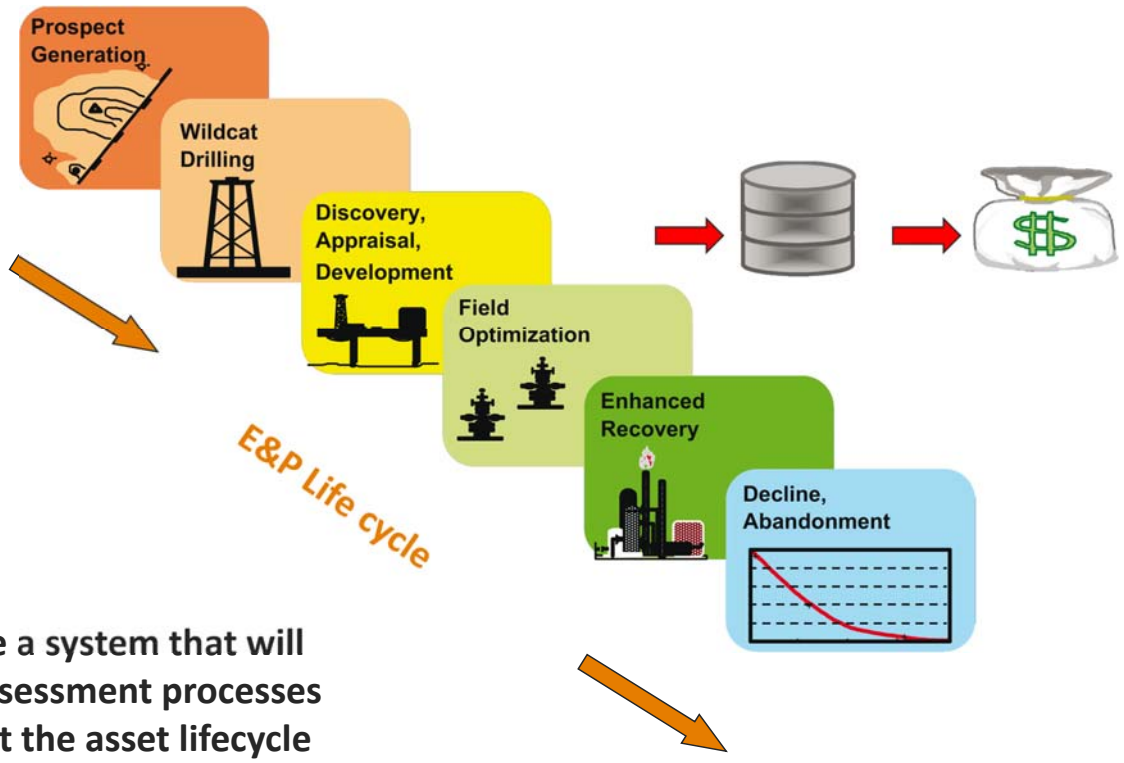
If somebody comes to you and says I have 1 Million Dollars?



If somebody comes to you and says I have 1 Million barrels of oil reserve?

Scope of projects

To align with the hydrocarbon finding, developing and producing business!



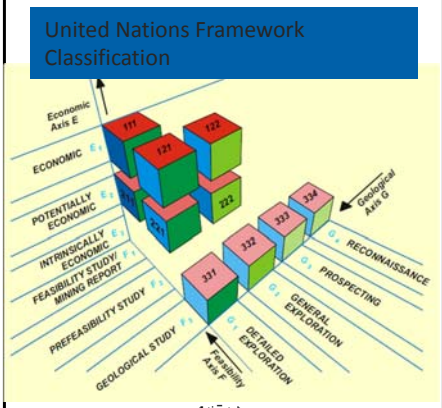
We require a system that will support assessment processes throughout the asset lifecycle

Reserves & international frameworks

US SEC

Protects investor's interest BUT does not capture complexity of today's technical environment

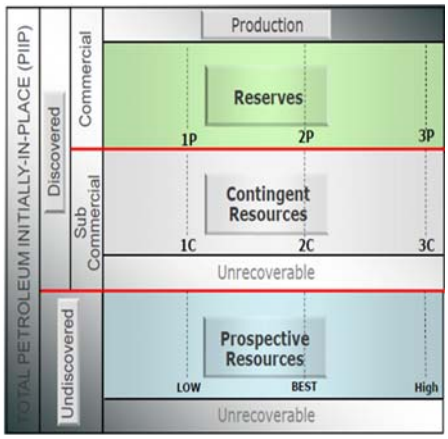
UNFC



UNITED NATIONS

Powerful for global assessment of energies BUT too complex & difficult to implement Audit Trail

SPE Based Systems



Project based & captures uncertainties,

Resource classification - A system in evolution……

- **1936 API (American Petroleum Institute) early oil reserves definitions and started using the term "proved reserves"**
- **1946 AGA (American Gas Association) definitions for natural gas and joined API in annual reserves reports for U.S.**
- **1964 SPE adopted proved reserves definitions similar to API**
- **1978 U.S. SEC issued definitions for proved reserves**
- **1981 SPE approved revised definitions for proved reserves**
- **1983 WPC (World Petroleum council) issued expanded definitions for reserves and procedures**

Resources classification – a system in evolution……

- 1987 SPE published definitions for unproved categories, probable and possible reserves
- 1997 SPE/WPC jointly adopted definitions for proved, probable, possible and deterministic and probabilistic methods
- 2000 SPE/WPC/AAPG (American Association of Petroleum Geologists) approved petroleum resources definitions
- **2001 SPE Guidelines for the evaluation of petroleum reserves and resources**
- **2007 SPE/WPC/AAPG/SPEE "Petroleum Resource Management System" (PRMS)**
- **2009 SEC Modernization of Oil and Gas reporting**
- **2009 SEC C&DIs Compliance & Disclosures Interpretations**
- **2011 SPE/WPC/AAPG/SPEE/SEG – Guidelines for Application of the PRMS**

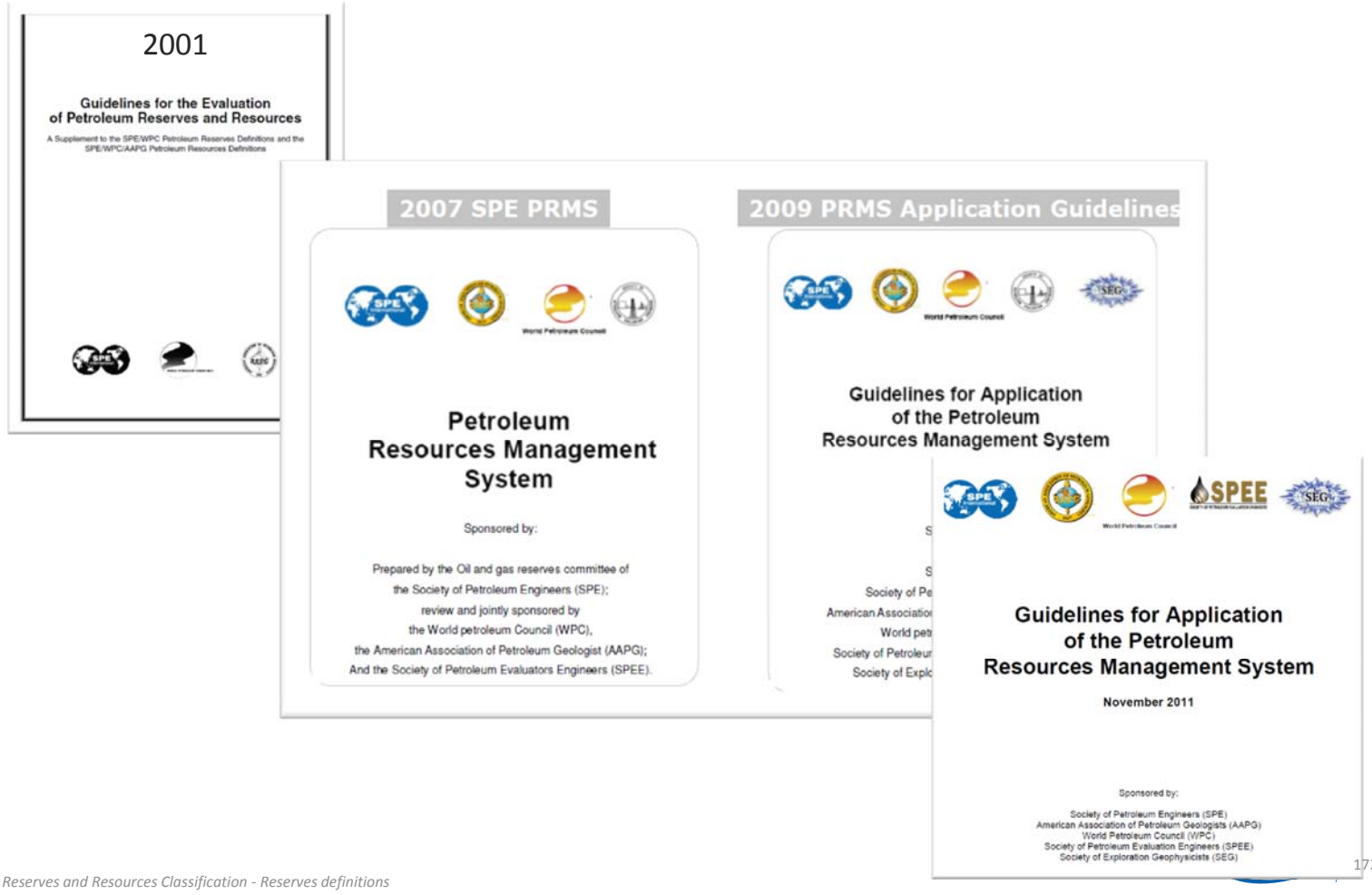
Reserves definitions

- Petroleum Resources Management System
- Endorsed by SPE/WPC/AAPG/SPEE/SEG

Extracted from a presentation prepared by the SPE Oil & Gas Reserves Committee (OGRC)

SPE : Society of Petroleum Engineers
WPC : World Petroleum Council
AAPG : American Association of Petroleum Geologists
SPEE : Society of Petroleum Evaluation Engineers
SEG : Society of Exploration Geophysicists

SPE leadership in developing standards for Petroleum



PRMS main principles

- The system is project based
- Supports the E&P asset life cycle
- The classification is based on chance of commerciality
- The categorization is based on range of uncertainty
- Base case uses evaluator's forecast of future conditions
- Applies to both conventional and unconventional resources
- Provides more granularity for project management
- Estimates based on deterministic and/or probabilistic methods
- Reserves are estimated in terms of the sales products

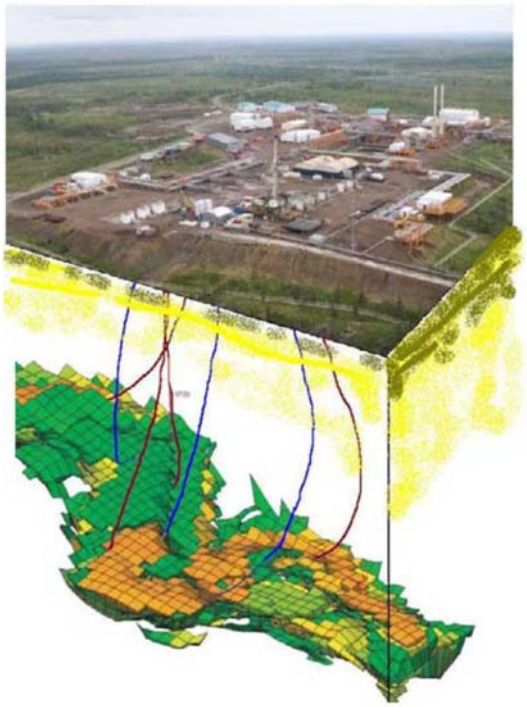
Project identification

- RRMS system is project based .

Facilities

Wells/recovery mechanism
(new, additional, EOR-IOR)

Reservoir / OIIP
(field/reservoir/panel)

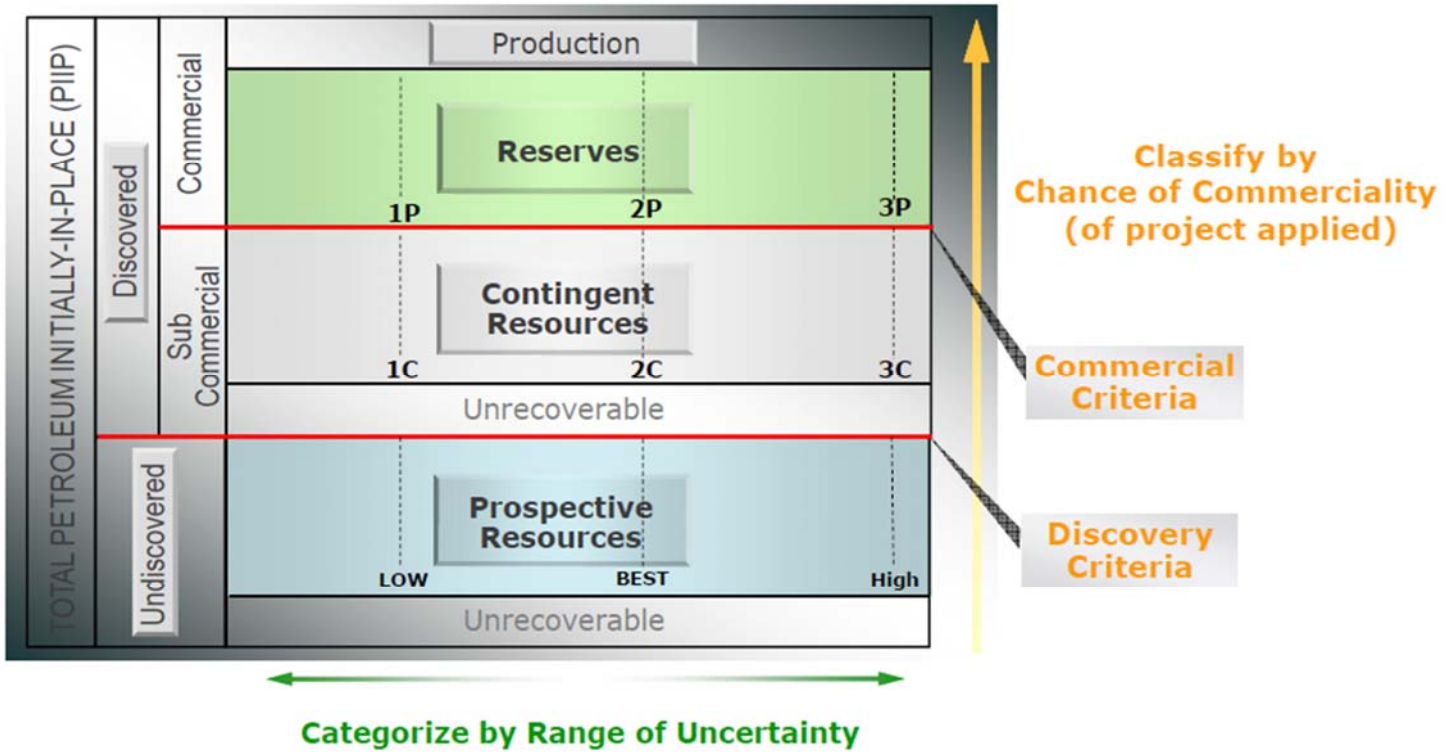


Economics
(CAPEX/OPEX/…)

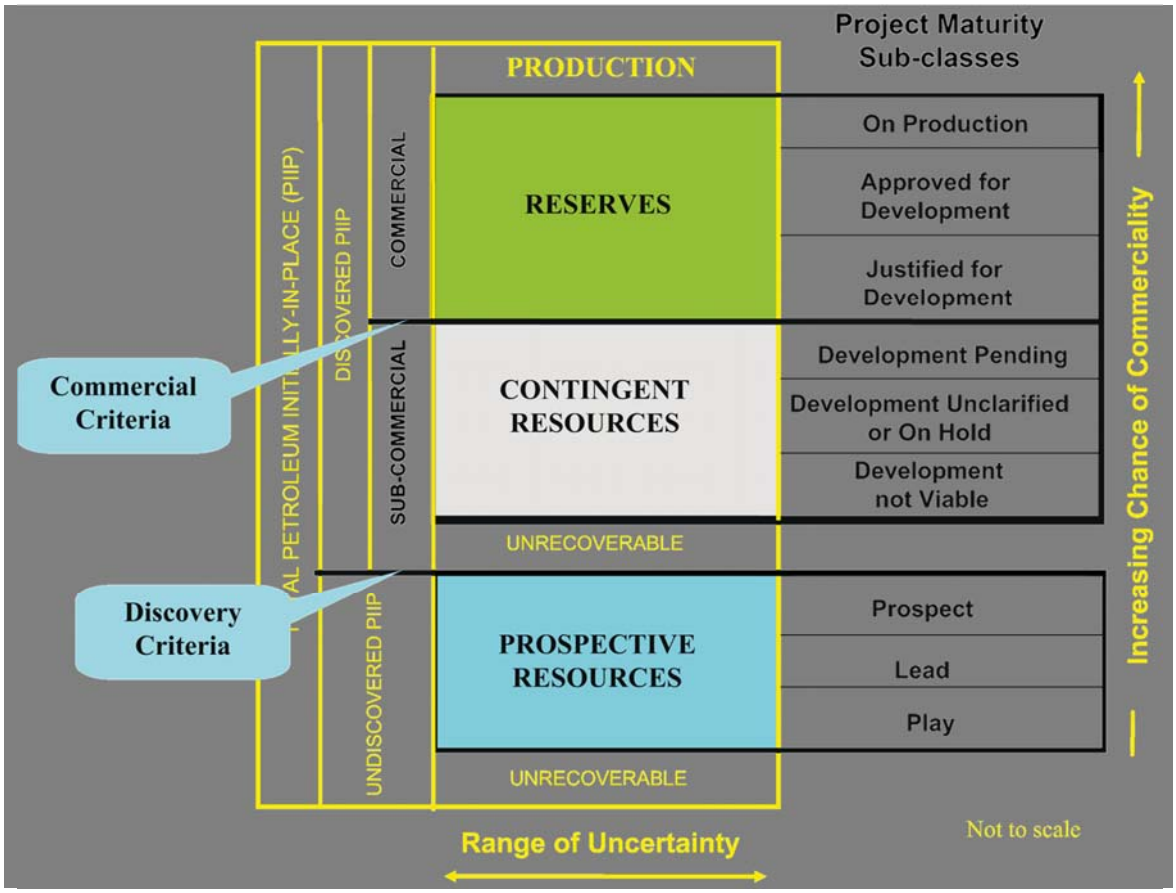
Contract
(PSAs- taxes, duration)

Environmental aspects

PRMS Matrix separates classification & categorization



Sub-classify by project maturity



Reserves definitions

US Securities and Exchange Commission

Conditions to have PROVED Reserves (1P):

- **Known reservoir (faults blocks may be an issue)**
- **Known fluids and contacts (PVT data and seismic may help)**
- **Known productivity (production test or logs plus analog)**
- **Known drainage mechanism (enhanced recovery may require a pilot or a an analog - at least for SEC)**
- **Firm development plan**
- **Known contractual conditions (gas contract - FID within 3 years)**


Federal Register

Wednesday,
January 14, 2009

Part II

Securities and Exchange Commission

17 CFR Parts 210, 211 et al.
Modernization of Oil and Gas Reporting; Final Rule

Proved reserves (1P): SEC compliance

- **Testing**
  - Economic productivity supported by actual production or conclusive formation test (MDT not sufficient)
  - Gulf of Mexico exemption:
    - Log, core, MDT and seismic may suffice
- **HDT / WUT (LKH / HKH)**
  - Proved in well
- **Continuity of production**
  - 1P for undrilled units only if certainty of continuity of production
- **Improved recovery**
  - Injection or EOR need pilot or analogue (same reservoir in the area)
- **Commitment to develop**
  - SEC proved reserves must be economic: signed sales contracts for gas
  - Request for proposals to build facilities,
  - Firm plans and timetables...
  - A lack of progress may be an evidence of a lack of commitment

SEC compliance

Areas where compliance could be an Issue

- **Lowest known hydrocarbons**
  - Contact information must be established by well penetration
  - Use of RFT / MDT pressure gradient data to establish contacts may not be acceptable
- **Probabilistic assessments**
  - Probabilistic methodology may be used, provided reported volumes comply with their proved definitions.
  - Difficult to tie results of probabilistic assessments to specific map locations

SEC Compliance

Regulatory reporting requirements for hydrocarbon reserves

- **Reporting requirements for companies listed on US stock exchanges.**
- **SEC Section SX 4-10 establishes definitions for proved reserves.**
- **The FAS (Financial Accounting Standard) 19 & 69 adopted by the SEC and provides the format and content for required reporting.**
- **Clear SEC's instructions for the classification of the proved reserves.**
- **SEC's audits are conducted on a regular basis to ensure compliance.**

[7] Rule 4-10(a) of Regulation S-X defines proved oil and gas reserves as "the estimated quantities of crude oil, natural gas, and natural gas liquids which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions, i.e., prices and costs as of the date the estimate is made. . . . Reservoirs are considered proved if economic productibility is supported by either actual production or conclusive formation test."

Reserve definition

- **RESERVES are:**
  - COMMERCIALLY recoverable
  - KNOWN reservoirs
  - SPECIFIED techniques (Project FDP)
- **PRMS: Hydrocarbon resources classification by chance of commerciality**
  - Reserves
  - Contingent resources
  - Prospective resources
- **PRMS: Hydrocarbon resources categorization by range of uncertainty: 1P, 2P 3P.**
- **Proved reserved in SEC are KNOWN:**
  - Reservoir, PVT, contact, drive mechanism, FDP and contractual terms

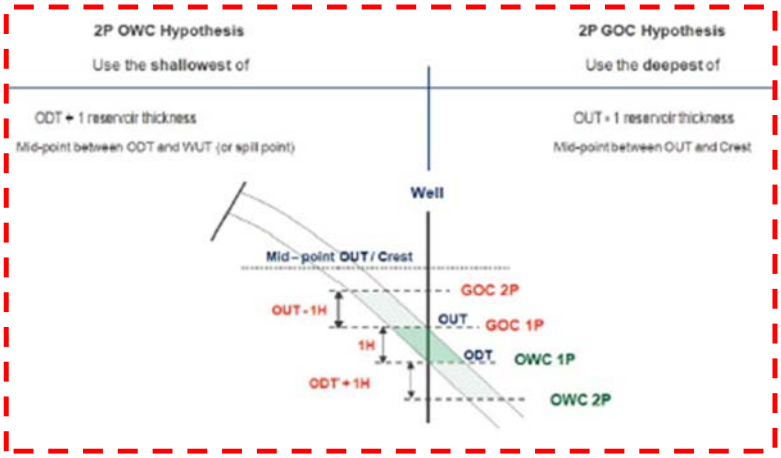
Notes

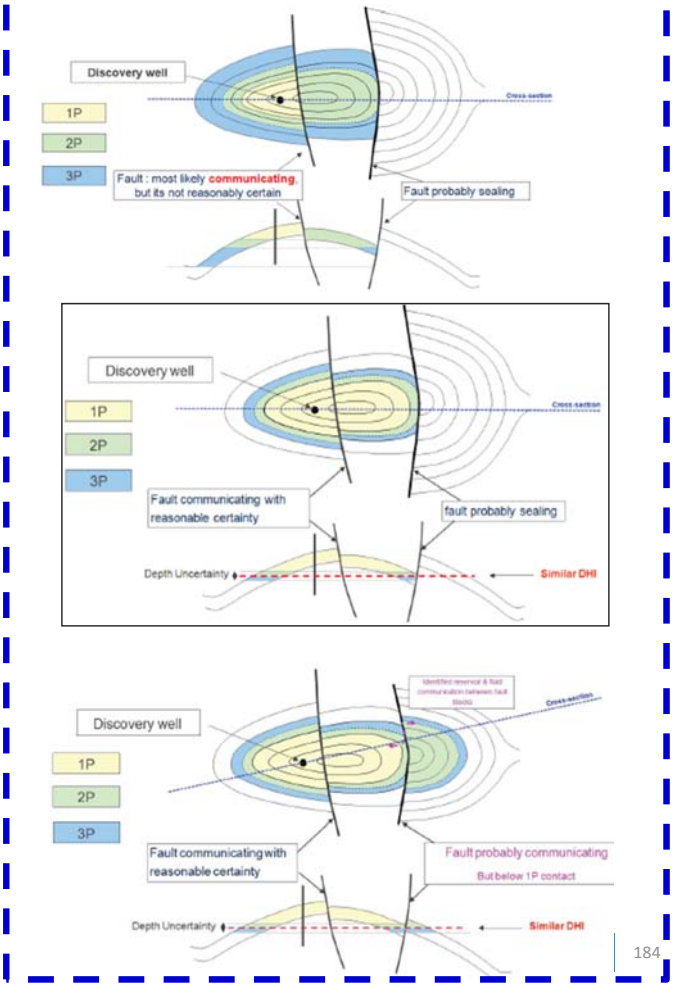
Reserves and resources classification

3. Practical guidelines

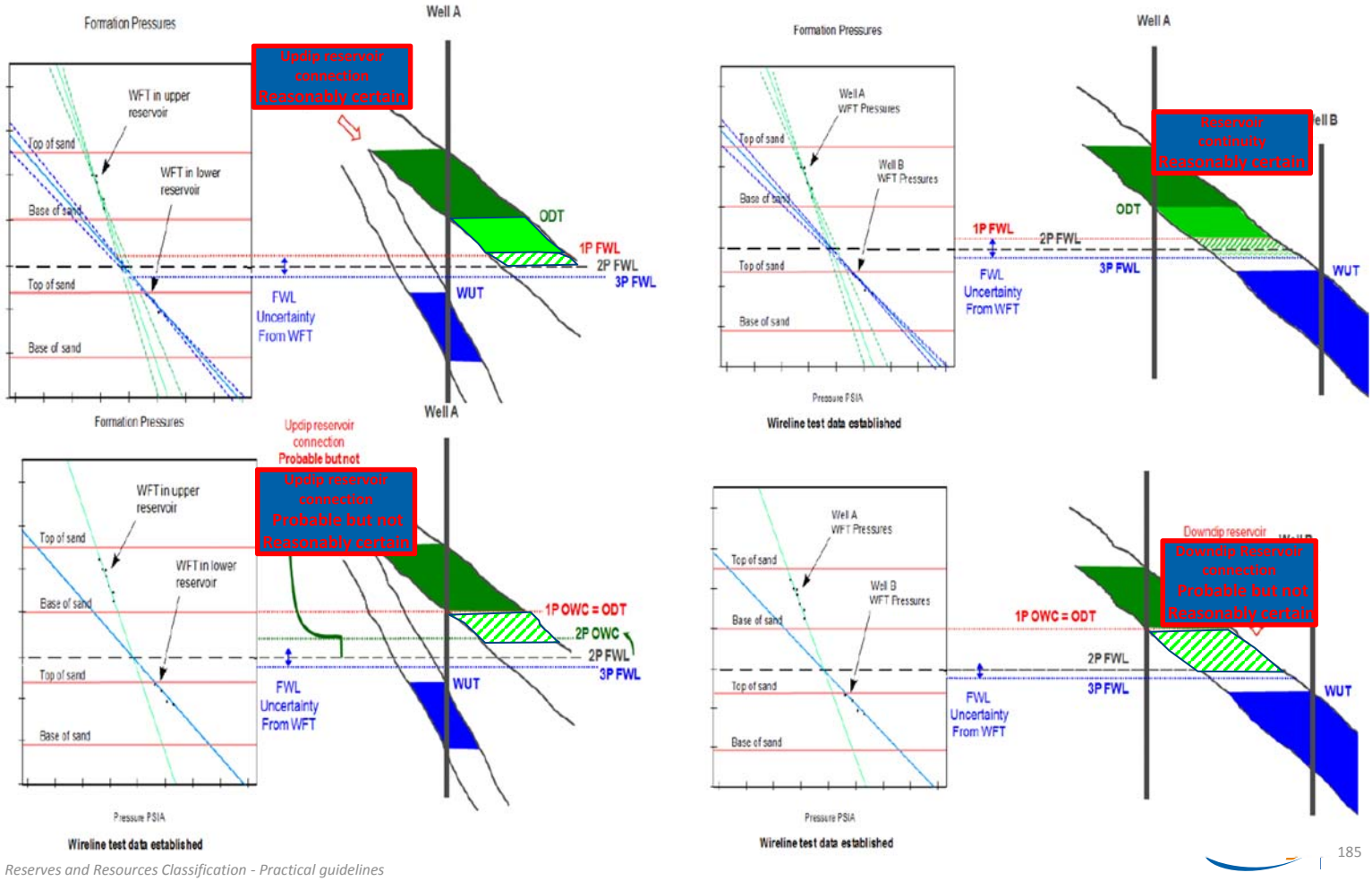
Proved + Probable Reserves (2P) & examples of definition

- **Reserves that are more likely than not to be recovered under… (P50)**
- **Compared to 1P:**
  - Adjacent fault blocks MAY be included
  - More flexibility on contacts ((ODT+WUT)/2, …)
  - Most likely recovery factor
  - Development decision within 10 years
- **Limited to license duration (as for 1P)**



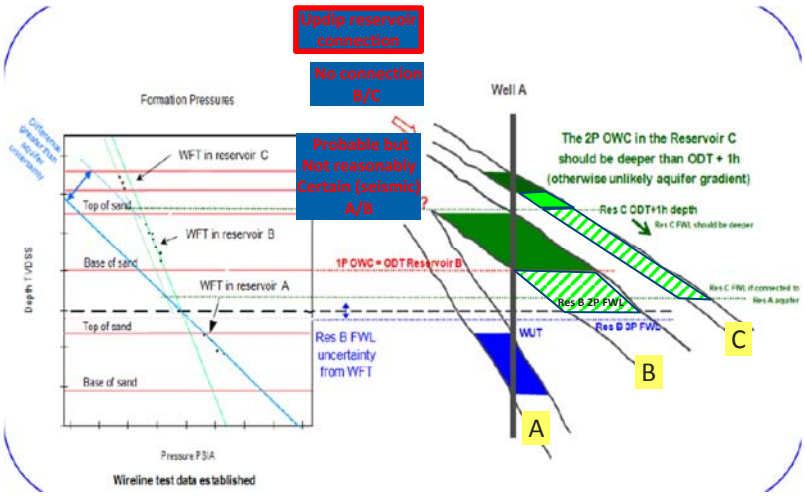


Examples of 1P/2P fluid column / WFT

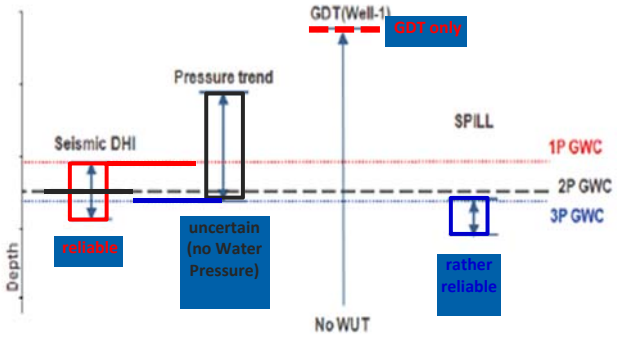


Examples of 1P/2P/3P evolution with delineation

Different levels with Hc and water
Regional aquifer trend known

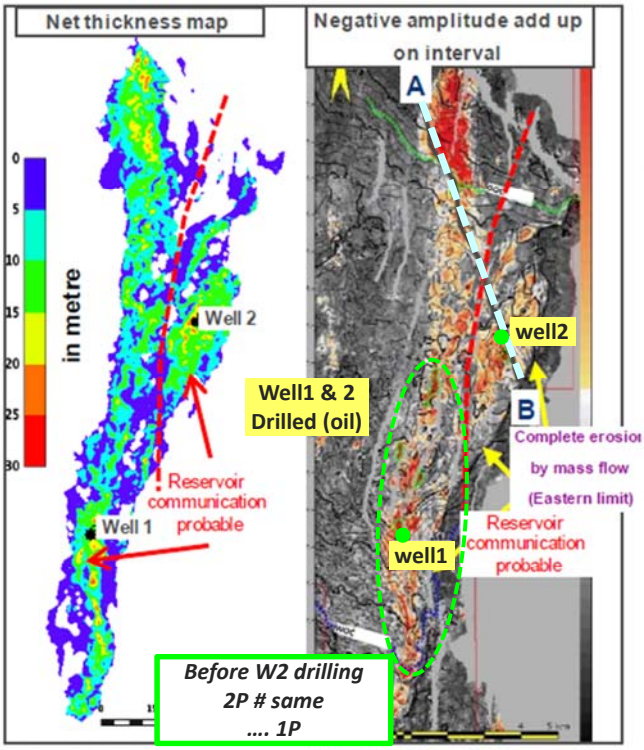


GWC Evaluation with different technologies (Gas field)

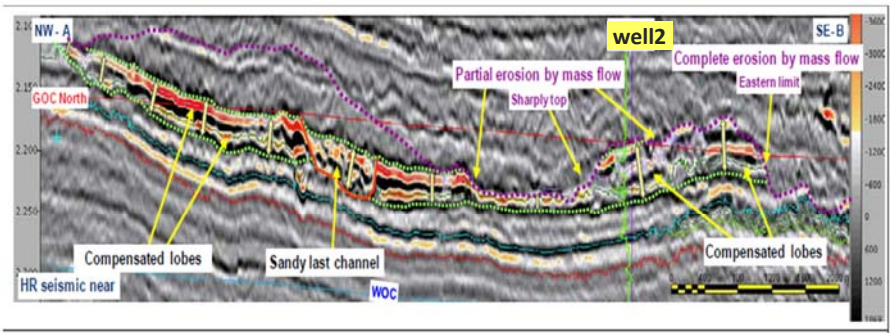


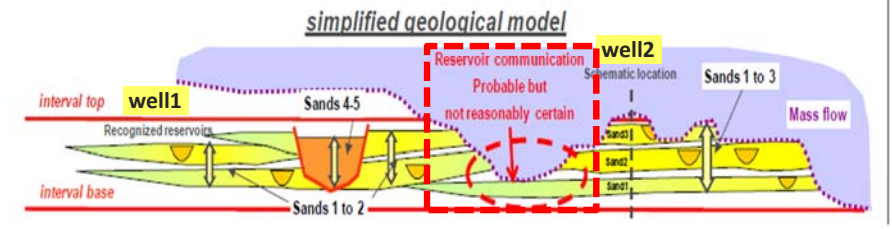
Example / Use of seismic attributes

Question: Communication of compartments proved by W1 & W2 ?



W1 & W2 drilled / oil proved / but …
Probable continuity (Seismic) through Sand1
However large erosion (mass flow)
Moreover lateral S1 extension W2/W1 not reasonably certain
→ continuity ?



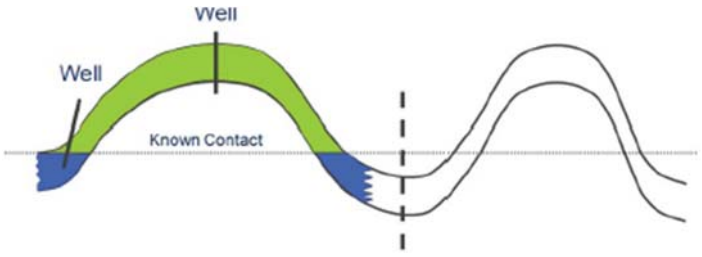


Continuity ? Sand 1 eroded & lateral extension ?

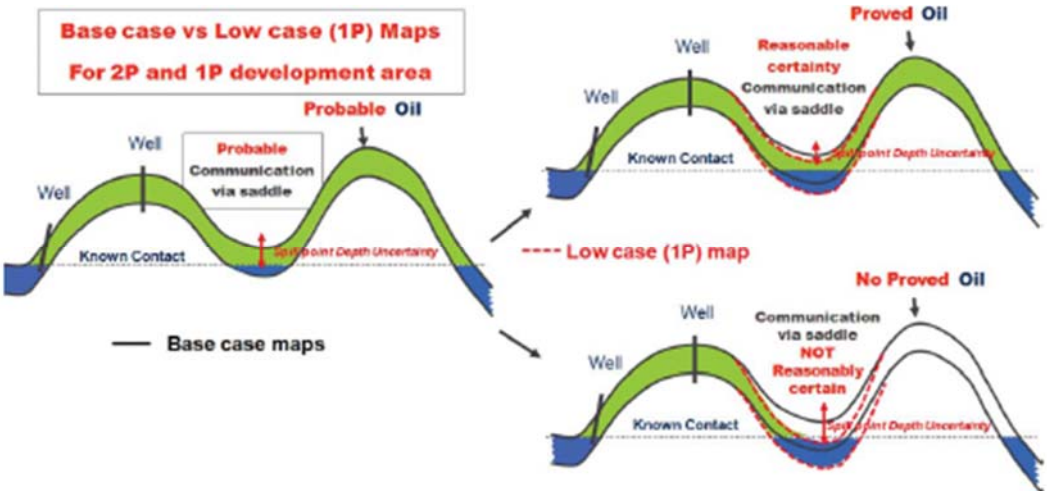
2P includes W1 & W2 compartments *(fluid & reservoir continuity probable)*
1P with 2 separated areas *(fluid & reservoir continuity not reasonably certain)*

Example of 1P/2P/3P evolution with delineation

1P & 2P reserves include the accumulation proved by the 2 wells
No relevant information on the spill point
2nd accumulation considered as Near-by Exploration (Resources)



The saddle location is defined with seismic more or less reliable/uncertain
2P includes the 2 accumulations as saddle is probably below OWC
1P includes or not the 2nd Accumulation whether or not saddle is reasonably or not reasonably below OWC

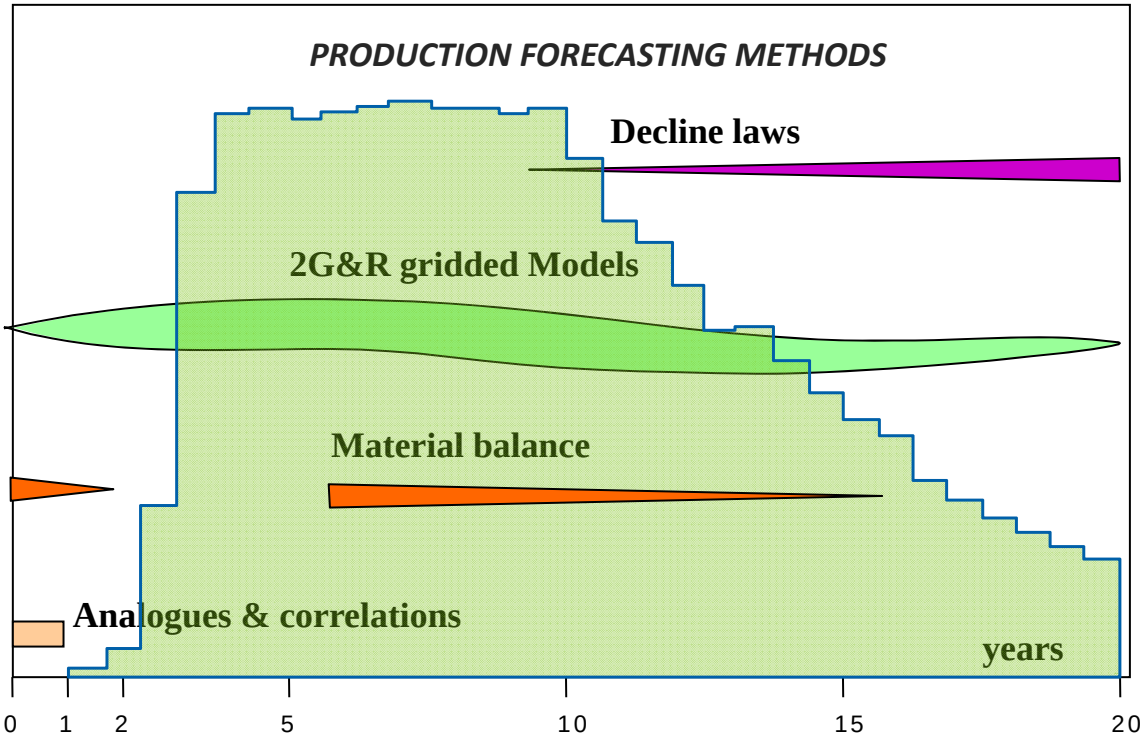


Reserves and resources classification

4. Production profiles

& reserve forecast tools

Methods for evaluations versus Field Status



Simplified methods
- Analogues correlations
- Analytical methods
- Material balance
- Decline curves

Comprehensive methods
Static & dynamic reservoir models

… and reserves, deterministic and/or probabilistic

A. Correlations examples and analogues

Solution gas drive fields - Recovery efficiency based on actual field results (68)

$$RF = 7.93 \log\left(\frac{k}{\mu_o}\right) + 0.373 \left(\frac{p_b}{p_a}\right) + 0.182\, S_{wi} + 0.149\, \Phi - 0.0006\, d - 0.0045 \left(\frac{R_{sb}}{B_{ob}}\right)$$

- RF is the recovery efficiency as % of the original oil in place
- k/ μ o dry air permeability divided by the oil viscosity (cp) at the bubble point
- Pb/Pa bubble point pressure (psia) divided by the abandonment pressure (psia)
- Swi connate water saturation, %
- Φ porosity, %
- d reservoir depth, ft
- Rsb / Bob solution gas oil ratio at bubble point (scf/stb) divided by the oil volume factor at bubble point (rb/stb)

A. Correlations examples and analogues

Water drive fields - Recovery efficiency based on actual field results (73)

$$E_N = 0.2719 \log(k) - 0.133 \log(\mu) - 1.5380\Phi - 0.0003488h + 0.25669 S_{wi} + 0.112130$$

- E_N is the recovery efficiency, fraction of the original oil in place
- k permeability , mD
- μ oil viscosity, cp
- S_{wi} connate water saturation, fraction
- Φ porosity, fraction
- h reservoir thickness, ft

B. Decline curve analyses

- **Decline curve analyses**
  - In many reservoirs, and particularly in older ones, data are insufficient for conventional material balance calculations or even more for dynamic reservoir simulation.
  - In such reservoirs, reserves estimates must be based mostly on the decline-curve analysis.
- **Decline-curve methods should be supplemented by other reservoir engineering tools, whenever possible.**
- **On the other hand, the decline-curve analysis can serve as a quality check of other types of calculations.**
- **Decline curve analysis (or Trend analysis) good use**
  - For a decline-curve to represent maximum accuracy, the operating conditions of the well, or the reservoir, must remain constant.
  - Observe and analyze trends (oil, gas rates, GOR, WOR, Pressure) vs time, injected volumes, cumulative productions, …
  - Estimate the decline rate

Decline curve analysis

- **The oil production rate of a field (or a well) cannot be sustained forever. A decline of oil production occurs over time because of:**
  - The decrease in reservoir pressure
  - The increase in WOR or GOR (Water or Gas production)

Decline Curve analysis = Derive a representative law from the historical data to be able to predict and extrapolate history

↓

Remaining Reserves Assessment

Field production predictions

Decline curve analysis

- **The mechanism and the operating conditions stay constant during the analysis period such as :**
  - New wells,
  - Production above and below the bubble point
  - Water injection
- **The analysis of the decline-curve is based on the :**
  - Decline rate defined as the fractional decline of the rate per unit of time ($\Delta q / q$):

$$D = -\frac{\Delta q / q}{\Delta t} = -\frac{dq / q}{dt}$$

  - If D is constant, then, as $dq / q = d \ln q$,

$$D = -\frac{d \ln q}{dt} = -\frac{2.3\, d \log q}{dt}$$

  - We can use a semi-log plot of rate vs time to estimate D.

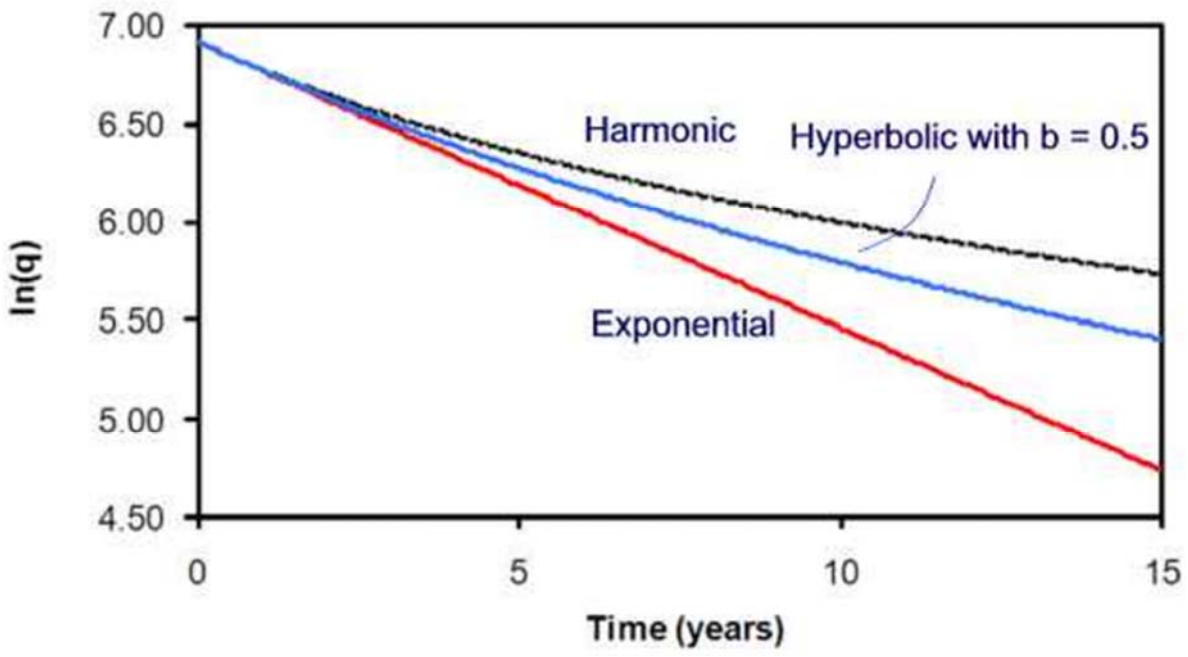
Decline analysis: standard nomenclature

q_0	Initial production rate at time t=0	b/d
q	Oil production rate at time t	b/d
q_e	Oil production rate at economic limit	b/d
t	Time	Year
D or a	Decline rate	% / year
Di or a_i	Initial Decline rate	% / year
Np	Cumulative Oil production at t	Stb
Ne	Cumulative Oil production at economic limit	Stb
b	Reciprocal of the decline curve exponent	0 < b < 1

Decline analysis

	Flow rate versus time	Cumulative production versus time	Flow rate versus Cumulative production
Exponential	$q(t) = q_0 e^{-Dt}$	$N_p = \frac{q_0}{D}\left[1 - e^{-Dt}\right]$	$q = q_0 - D \times N(t)$
Harmonic	$q(t) = \frac{q_0}{(1 + D\,t)}$	$N_p = \frac{q_0}{D} Ln\,(1 + Dt)$	$Ln\ q = -\frac{D}{q_0} \times N(t)$
Hyperbolic	$q(t) = \frac{q_0}{[1 + b\,D\,t]^{1/b}}$	$N_p = \frac{q_0}{D(1-b)}\left[1 - (1 + b\,Dt)^{\frac{b-1}{b}}\right]$	$q^{1-b} = 1 - \frac{D(b-1)}{q_0} \times N(t)$

Decline curves analysis



Oil reservoir - Decline curve analysis

Oil reservoir typical behavior

→ **Natural depletion:** *exponential*

curves q_o vs N_p

→ **Dissolved gas expansion :** *exponential or hyperbolic* (b # 0.3)

curves q_o vs N_p

→ **Gas cap expansion:** *Hyperbolic as long as gas oil contact has not reached perforations*

curves log GOR vs N_p

→ **Active aquifer :** *exponential*

curves f_w or WOR vs N_p

→ **Water injection:** *exponential* then *Harmonic*

curves f_o vs N_p rather than q_o vs N_p

At the end of field life: log f_o or log WOR vs. N_p

Hyperbolic	**This law applies particularly for solution gas drive, gas cap expansion, large gas caps, especially for tail productions (very mature fields)**
Exponential	**This law applies for initial decline. Forecasts are pessimistic for tail productions (very mature fields)**
Harmonic	**This law applies particularly for water drive, when BSW increases. This method is rather optimistic and is not convenient if solution gas drive is the main mechanism**

Production profiles & reserves forecasts tools

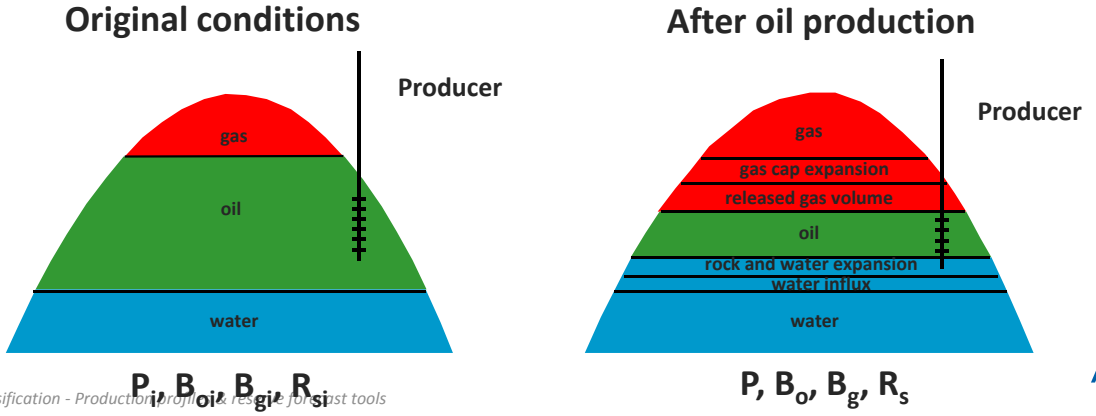
C. Material balance primary (mainly) & secondary recovery material balance

- **The material balance method is based on the conservation mass equation; it is a volume balance involving produced and injected fluids from/into the reservoir resulting in pressure changes controlled by the compressibility of the system (fluids & rocks)**

- **It is a basic tool for the reservoir engineer to:**
  - Check production data consistency
  - Check the consistency between the geological evaluation and the reservoir behavior (Fluid in place calculation)
  - Understand the reservoir behavior
  - To design a future complementary development plan
  - To forecast production and recovery

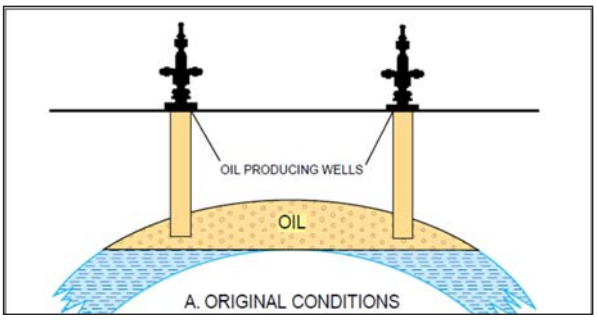
Generalized expression of the material balance

- The general form of the material balance equation can be written as:
- With: $$F = N(E_o + mE_g + E_{f,w}) + W_e B_w$$
- F , the underground withdrawal $$F = N_p(B_o + (R_p - R_s)B_g) + W_p B_w$$
- The expansion of the oil and its originally dissolved gas is $$NE_o = N[(B_o - B_{oi}) + (R_{si} - R_s)B_g]$$
- The term describing the expansion of the gas-cap is $$NmE_g = NmB_{oi}(\frac{B_g}{B_{gi}} - 1)$$
- The expansion of the connate water & reduction in the pore volume is $$NE_{f,w} = N[(1+m)B_{oi}(\frac{c_w S_{wc} + c_f}{1 - S_{wc}})\Delta p]$$
- The term describing the water entries is $W_e B_w$



Undersaturated oil reservoir

Monophasic expansion



- In the general case of a monophasic expansion:
  - We have $$N_p B_o = NB_{oi}[\frac{B_o - B_{oi}}{B_{oi}} + \frac{C_w S_{wc} + c_f}{1 - S_{wc}}\Delta p]$$
  - Knowing $$c_o = \frac{B_o - B_{oi}}{B_{oi}\Delta p}$$
  - And regrouping $$c_e = \frac{1}{1 - S_{wc}}(c_o S_o + c_w S_{wc} + c_f)$$
  - The mat bal equation is then $$N_p B_o = NB_{oi} c_e \Delta p$$

Pi>Pb
Pf>=Pb

- If C_w and C_f are negligible, then $$N_p B_o = N(B_o - B_{oi})$$

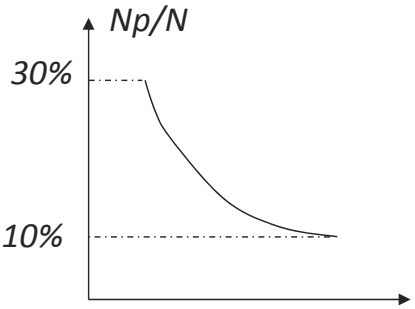
- The recovery from the monophasic expansion is very low: a few %

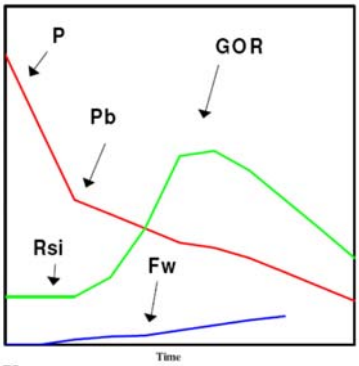
Solution gas drive

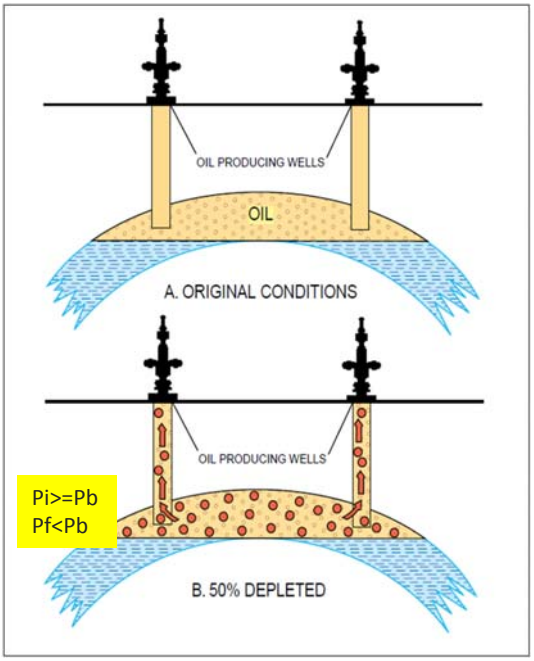
- **The material balance equation can be simplified as:**

$$\frac{N_p}{N} = \frac{(B_o - B_{oi}) + (R_{si} - R_s)B_g}{B_o + (R_p - R_s)B_g}$$

- **There is an inverse relationship between the oil recovery and the cumulative gas oil ratio Rp.**







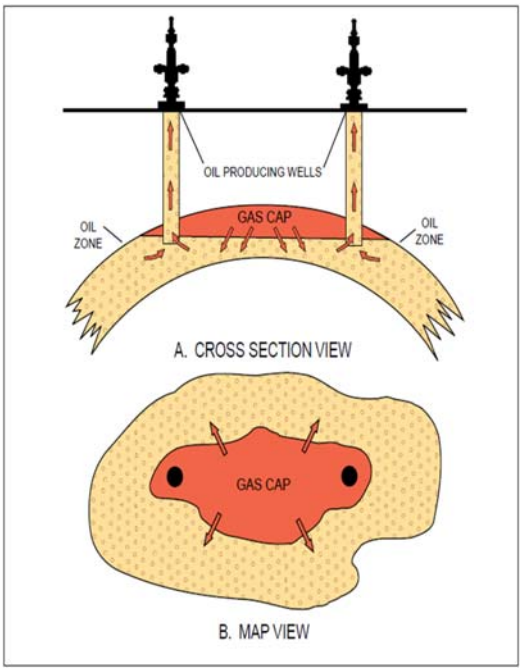
- **Conclusion: to obtain a good recovery, as much gas as possible should be kept in the reservoir.**

Gas cap drive

- With some assumptions, the material balance equation can be written as:

$$N_p[B_o + (R_p - R_s)B_g] = N[(B_o - B_{oi}) + (R_{si} - R_s)B_g + mB_{oi}(\frac{B_g}{B_{gi}} - 1)]$$

- In which the right hand side contains the term describing the expansion of the oil plus originally dissolved gas together with the term for the expansion of the gas-cap gas.
- The equation is rather cumbersome and does not provide any clear picture of the principles involved in the gas-cap drive mechanism.
- However, because of the gas-cap expansion, the pressure decline is less severe than for a solution gas drive reservoir and generally the oil recovery is greater, typically in the range 25-35 %, depending on the size of the gas-cap.



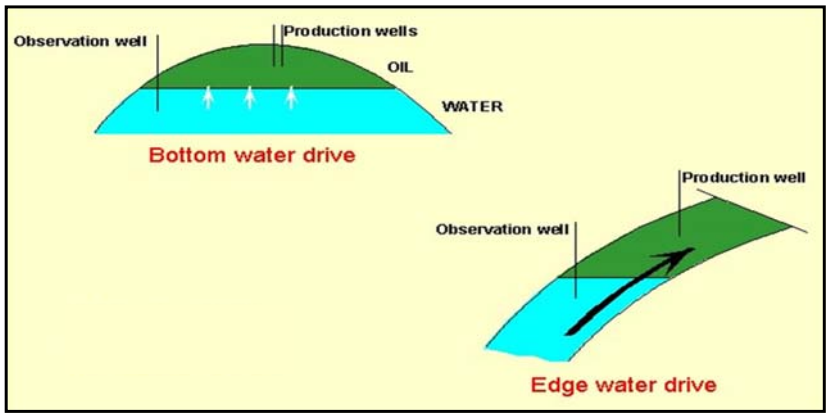
Oil reservoir with natural water influx

- **Production drive:**
  As the reservoir is depleted, water influx from the aquifer provides energy to produce the oil. The water movement comes from the pore compaction and water expansion in the aquifer.

Assuming P_b << P *(undersaturated oil)*

For a pressure drop $P_i \rightarrow P$, following a production N_P :

a) Oil volume expands
b) Water volume expands
c) Pore volume decreases
d) Aquifer expands => Water entry We
e) Water production Wp



Oil production = a + b + c + d – e

$N_pB_o = NB_{oi}C_e \Delta P$ + W_e - W_pB_w

''Monophasic oil expansion'' Equation | *Water Entry* | *Water Production*

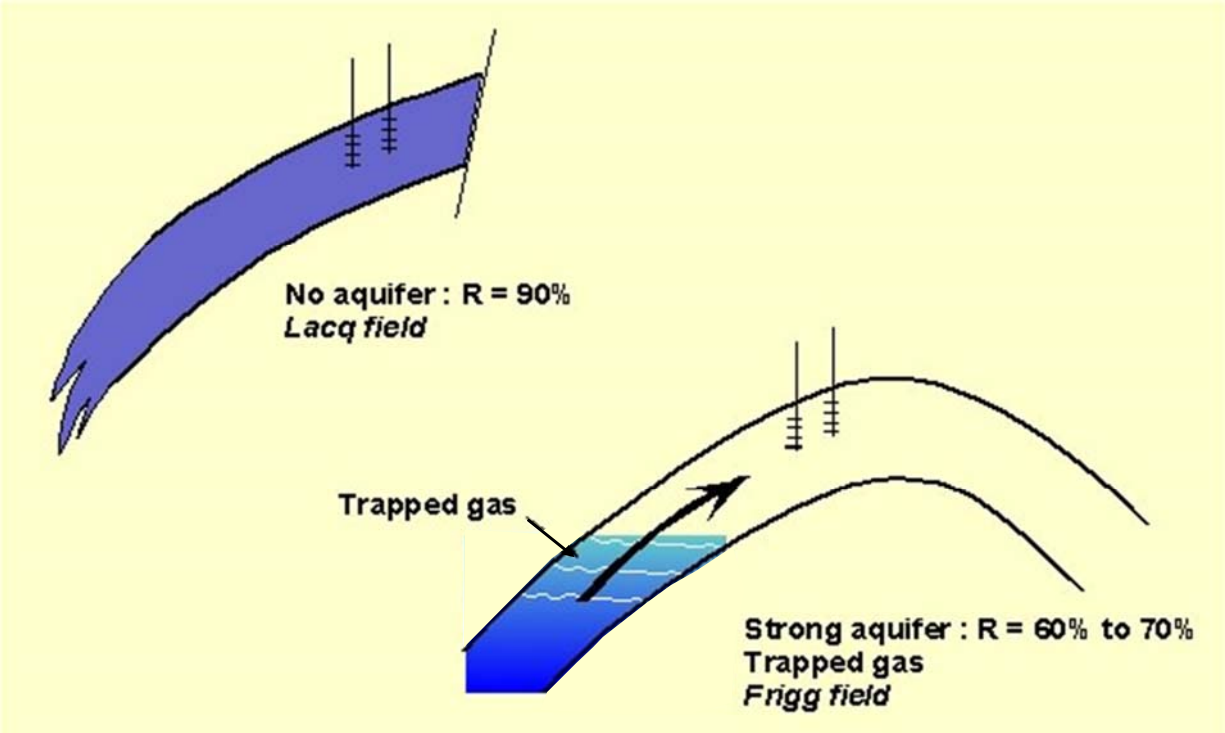
Compaction drive

- **As a reservoir gets depleted, its fluid pressure decreases (by Δp), hence the effective pressure on the rock grains increases (by Δp). Therefore the compaction of the rock is seen as a contraction of the pore volume ΔVf :**

$$\frac{\Delta V_f}{V_f} = c_f \Delta p$$

- **Where C_f, also called C_p, is the pore compressibility.**
- **For most rocks, C_f is of the order of 3 to 10 10-6 psi-1 .**
- **However, for some reservoirs, C_f can be much greater and compaction becomes significant as a drive mechanism.**

Material balance gas reservoirs



Gas field

With no water entry,

- **When pressure decreases from Pi to P, the volume occupied by the gas under reservoir conditions does not change. The material balance equation is:**

$$G\,B_{gi} = (G - G_p)\,B_g \qquad Gp = G\left(1 - \frac{Bgi}{Bg}\right)$$

G : initial accumulation at standard conditions

G_p : gas production at standard conditions

$B_{g,gi}$: Volumetric factor gas

$$\frac{Bgi}{Bg} = \frac{Zi}{Pi} \times \frac{P}{Z} \qquad Gp = G\left(1 - \frac{Zi}{Pi} \times \frac{P}{Z}\right)$$

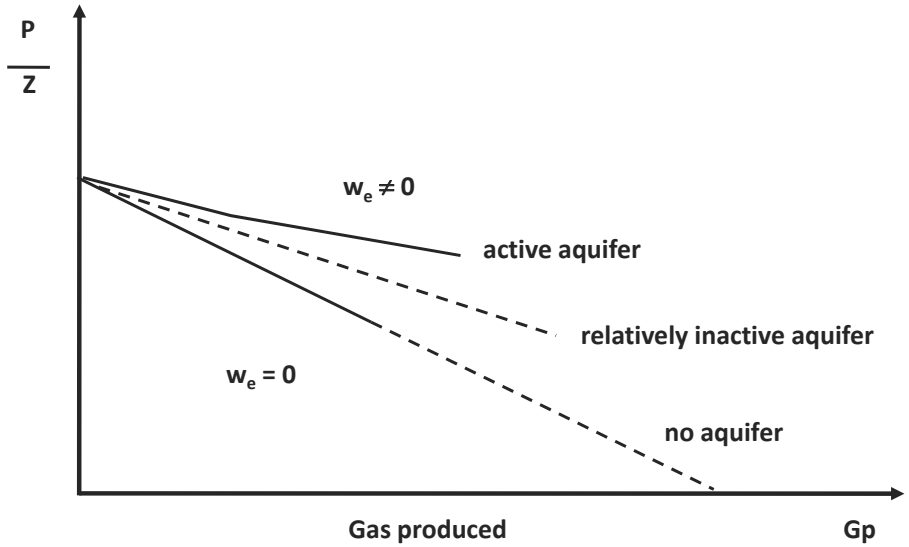
With water entry,

- **The material balance equation becomes:**
  - G Bgi = (G - Gp) Bg + We - Wp
  - We: water entries from the aquifer
  - Wp: water production

$$Gp = G\left(1 - \frac{Zi}{Pi} \times \frac{P}{Z}\right) + \frac{We - Wp}{Bg}$$

Gas field

- **In case of active aquifer (water entry), the straight line becomes exponential:**



- **Be aware of a wrong evaluation of the gas in place, if no aquifer action detected!**
- **Necessity of observation wells.**

Summary

- **Natural drainage mechanisms for oil reservoirs:**
  - Monophasic expansion — RF few %
  - Solution Gas Drive — RF 10-25 %
  - Gas cap drive — RF 25-35 %
  - Natural water drive — RF up to 50-60 %
  - Compaction drive — RF 0-20 %
- **Natural drainage mechanisms for gas reservoirs:**
  - No aquifer — RF 60 to 95 %
  - With active aquifer — RF 50 to 70 %

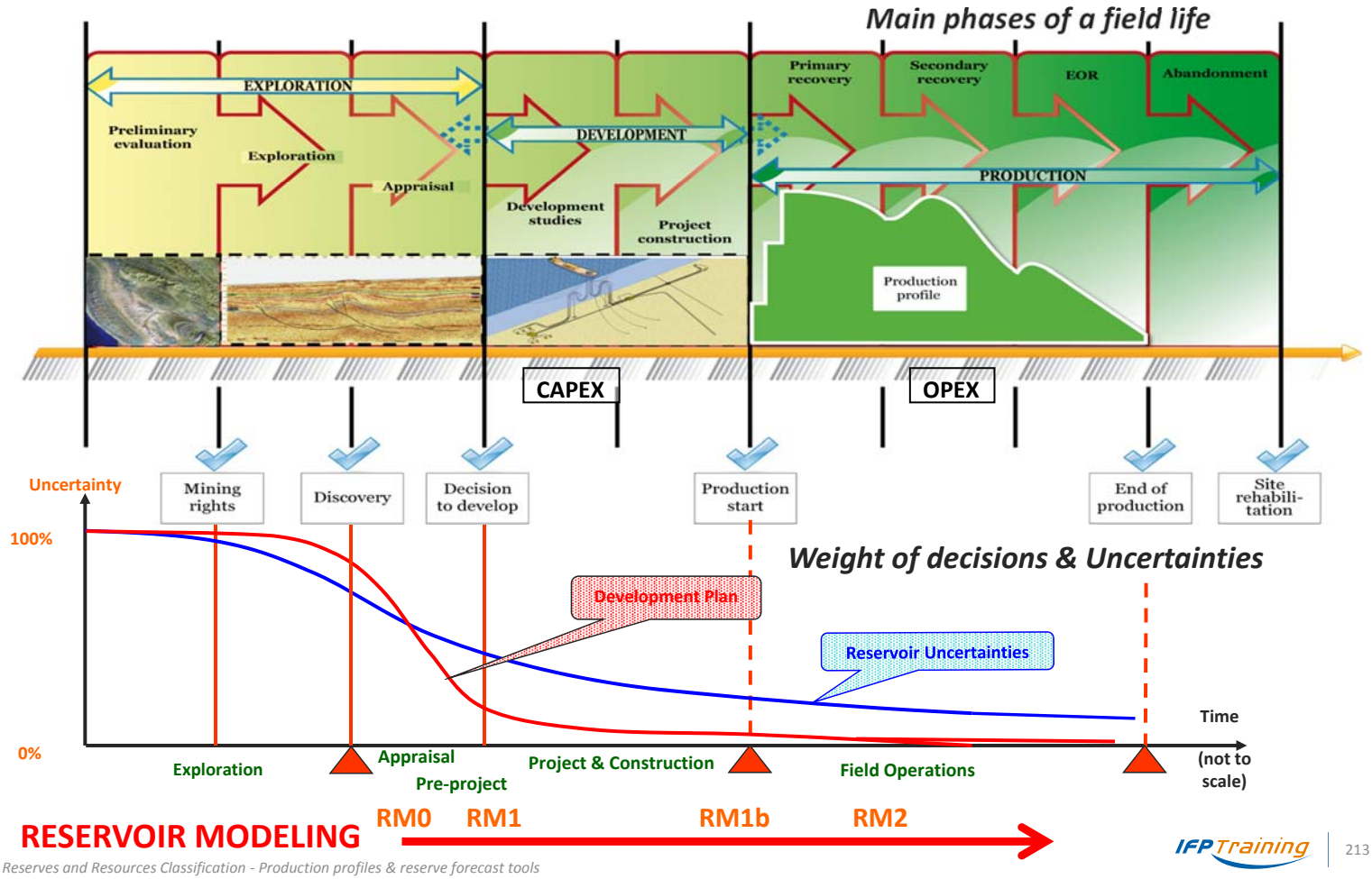
D. Dynamic reservoir modeling

- **The practical use of numerical models started to expand in the sixties related to computer development, as before, analytical methods were prevailing**
- **Nowadays, the petroleum companies systematically use models:**
  - Before making a decision on a new field development
  - To help in the location of new development wells (infill)
  - Before initiating secondary and tertiary processes
- **A reservoir simulation model is an effective reservoir management tool thanks to the integration of:**
  - Specific geological and geophysical works (logs, seismic 4d, …)
  - Specific engineering works: laboratory and field (MBA, well test analysis)
  - Detailed uncertainty evaluation: experimental design
  - Production & injection data
- **A necessary synergetic approach leading to integrated 2G&R studies**

Why run a flow simulation?

- **Main drivers:**
  - To overcome simplifying assumptions (used in hand & analytical calculations)
  - To consider realistic problems (development plan, production history, …)
  - To take all the available data into account and to better understand all their interactions for a given scenario
  - To perform sensitivity to unknown parameters and address impacting uncertainties
- **Main use:**
  - Help to decision, in particular at the end of the appraisal (concept scenario) and pre-development phases (FID)
  - Establish reliable production forecasts and resources / reserves
  - To optimize the production profiles and the final recovery after production start-up (infill drilling, workovers…) while reservoir knowledge improves

When run a flow simulation?



When run a flow simulation?

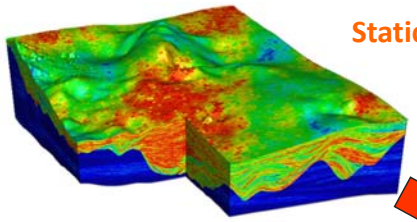
- **Appraisal**
  - To identify the most impacting dynamic uncertainties
  - To define the appraisal needs (structural, contacts, faults, facies variations)
- **Non producing reservoir**
  - To identify efficient recovery mechanisms and select a concept scenario
  - To define the well schema (facilities) & to optimize Capex
- **Producing reservoir**
  - To integrate history data & to improve reservoir description
  - To optimize oil production and recovery (complementary development)
- **In all the cases**
  - To establish reliable production forecasts & resources/reserves

Dynamic reservoir simulation

- **At all the stages of the field development, essential questions need to be addressed in order to be able to evaluate how much hydrocarbons will be produced through time:**
  - How much hydrocarbon is in the reservoir?
    - ↳ OHIP
  - How much of that hydrocarbon can potentially be recovered?
    - ↳ RESOURCES / RESERVES
  - How quickly can the recoverable hydrocarbons be produced ?
    - ↳ PRODUCTION PROFILES
  - How will the reservoir perform under various development scenarios?
    - ↳ SENSITIVITY RUNS
- **A dynamic reservoir model is a useful tool that may help to answer those questions.**

Reservoir simulation / A GSR integrated process

- **Integration of 2G & reservoir data - Integration of technologies**

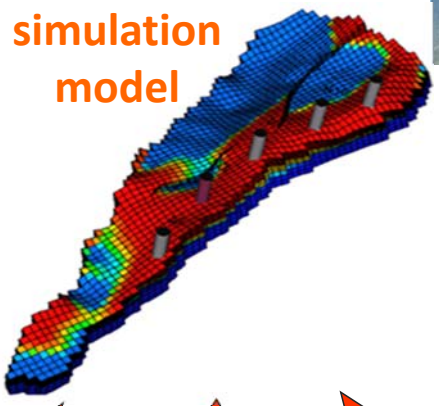


Static reservoir description / Geological model

Facilities



Reservoir simulation model

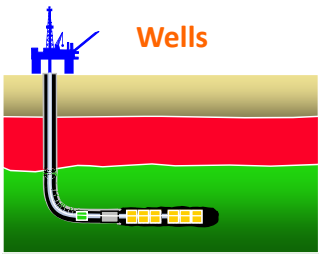


Equations mass conserv. / flow

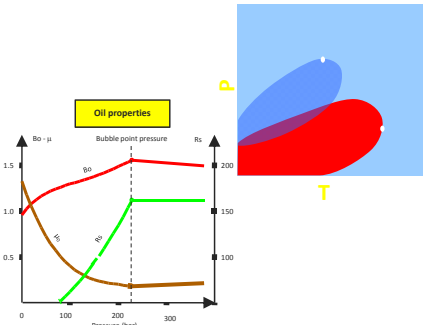
$$\frac{\partial}{\partial t}\left(\phi\sum_p C_{ip}\rho_p S_p\right) - div\left(\sum_p C_{ip}\rho_p V_p\right) - \delta q_i = 0$$

$$Vp = -\frac{Kk_{rp}}{\mu_p} grad\left(P_p + \rho_p gz\right)$$

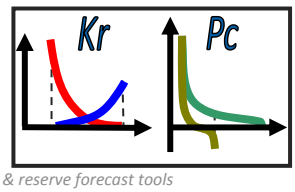
Wells



Fluid properties

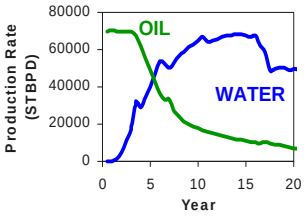


Polyphasic flow

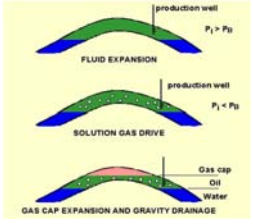


AQUIFER

Production data



Drive mechanisms



Numerical models

Main parameters & modeled phenomena

- **Reservoir properties (volumetric)**
  - Gross volume: Vt (from geol model upscaled – Tops/ gross Ht)
  - Net volume: Vu (from geol model upscaled - NTG)
  - Porous volume: Vp (from geol model upscaled - porosity)
  - Pore compressibility: Cp
- **Fluid properties (in reservoir conditions)**
  - Liquid vapor equilibrium (pressure & saturation)
  - Density, viscosity
  - Compressibility

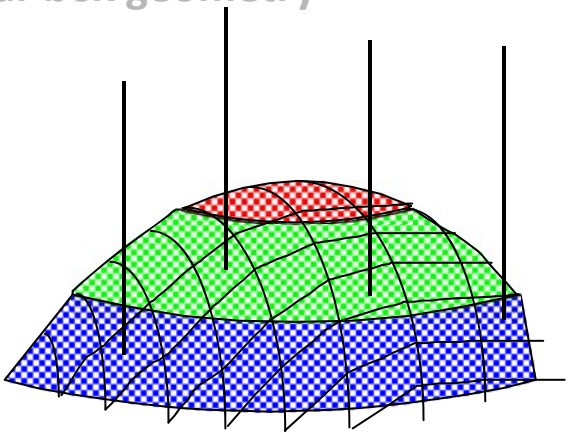
  } for each phase (O/G/W)
  - Compositions (compositional model Zi (mixture) Xi (liquid) Yi (vapor))
- **Flow (in reservoir conditions)**
  - Permeability (H & V)
  - Relative permeability and capillary pressure

Reservoir simulation model

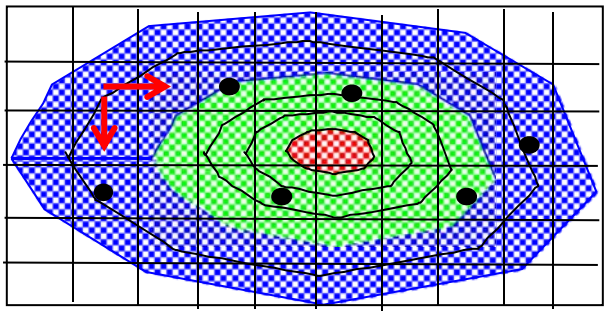
- **Processing of flow equations, mathematical expression adapted to computer treatment, needing double discretization**
  - Spatial discretization: grid with one value per block/cell for each reservoir parameter (porosity, Kx/Ky/Kz, NTG, Fluids saturations)
  - Time discretization: time steps for production data & transfer/ diffusion calculations between blocks
- **Numerical simulator models:**
  - Black Oil , Compositional, Chemical, Double Porosity, Thermal
  - Branded processors: ATHOS, ECLIPSE, VIP, FRAGOR, STARS…

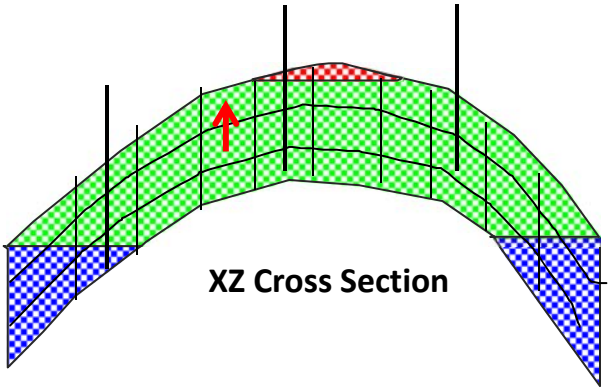
Numerical models: spatial & time discretization

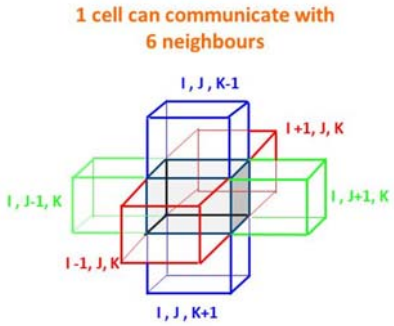
Sugar box geometry



3D View

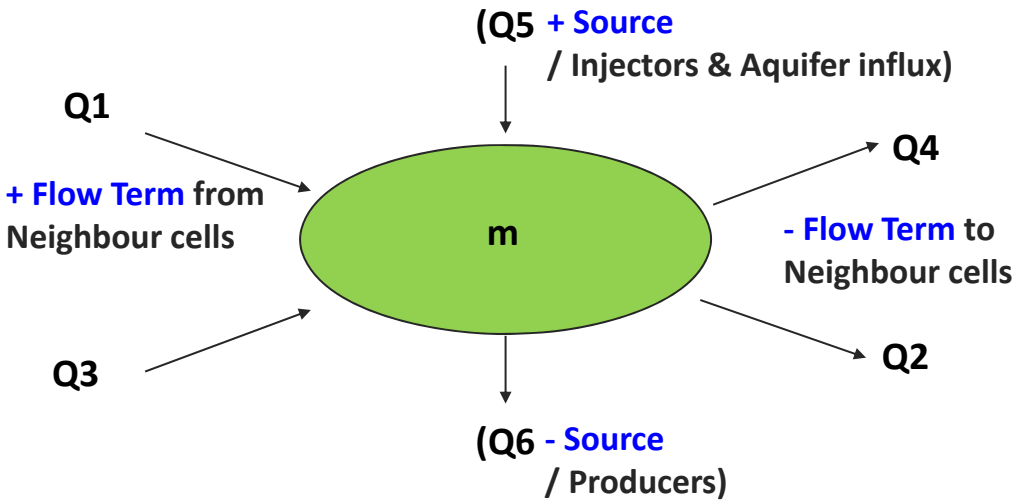


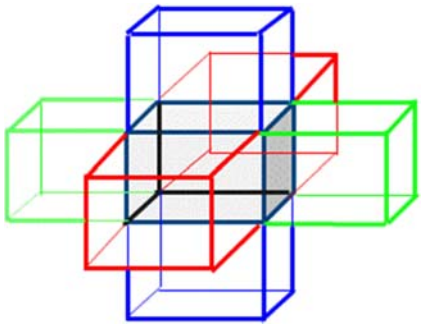




Numerical simulators

- **Material balance equation in a cell**





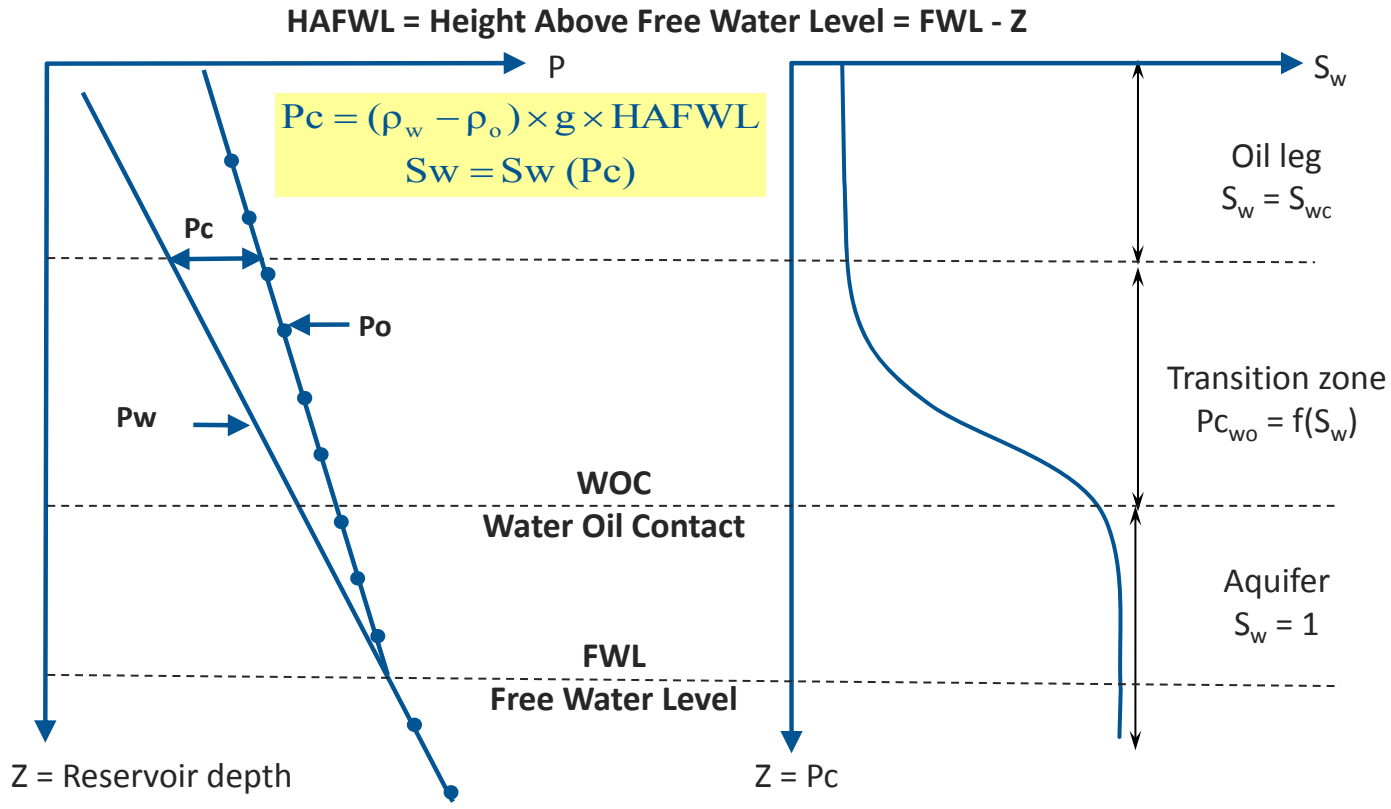
$$Q1 + Q2 + Q3 + Q4 + Q5 + Q6 = \Delta m$$

Flow Term = Accumulation Term

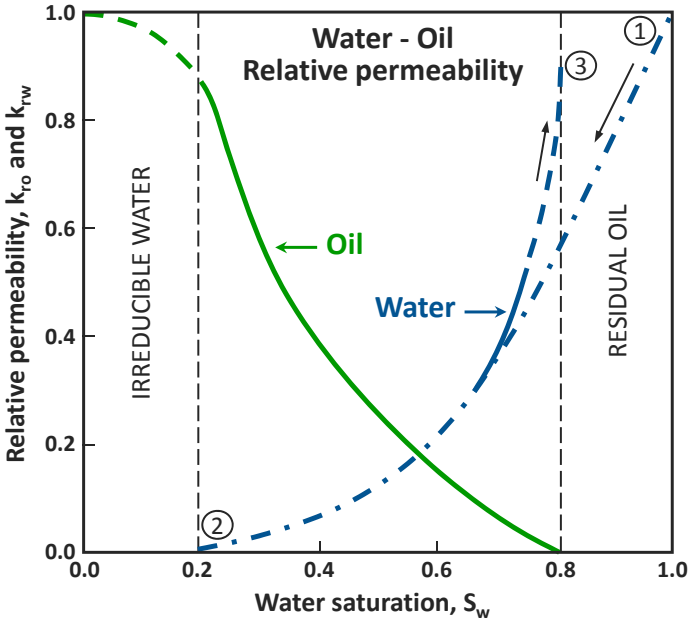
Initial state

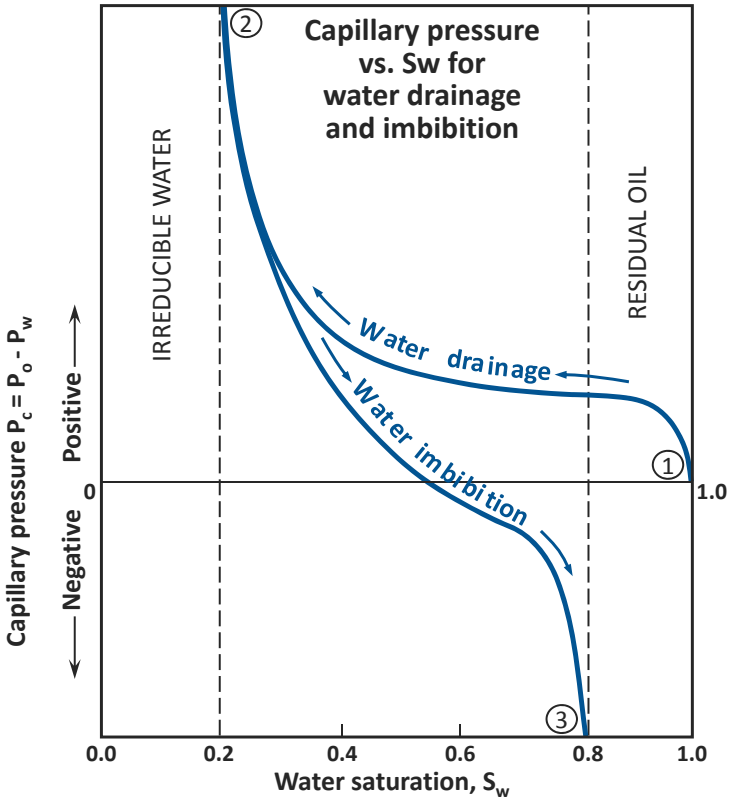
- **The reservoir is in static equilibrium**
- **The objective is to set up:**
  - initial pressures
  - initial saturations
- **The initial state is correct when the original volumes in place are correctly calculated (comparison Static / Flow models)**
- **Main data influencing the original volumes in place are:**
  - The net pore volume
  - The saturation height functions (influenced by Pc curves and fluid densities)

Initial state: pressure & saturation profiles



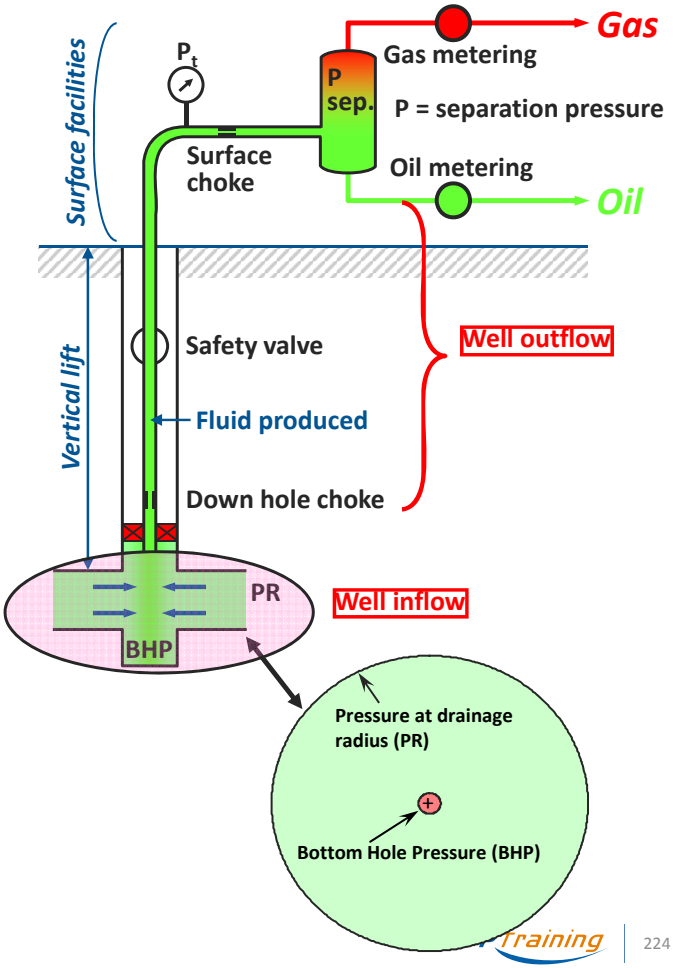
Saturation functions



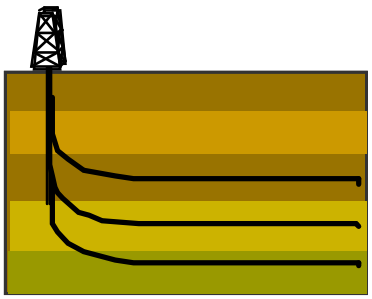


Some data on well description

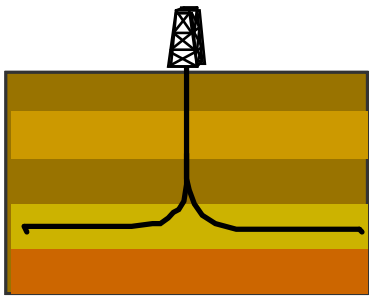
- **Well geometry**
  - Well radii are very small compared to well cells (~1/1000)
  - Wells are considered as source points in the well cells
- **Inflow performance**
  - Geometry of thet perforated intervals
  - Inflow performance relationship per perforated interval
- **Outflow performance *(for forecast generally)***
  - Pressure drop through the tubing and surface installations
- **Well control *(for forecast generally)***
  - Production schedule (oil rate, gas rate, reservoir voidage, …)
  - Minimum bottom hole flowing pressure
  - Minimum well head flowing pressure



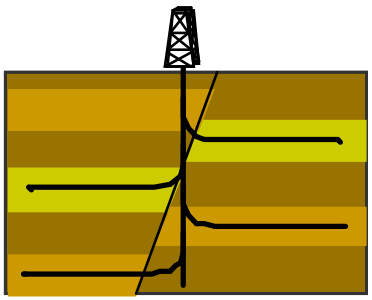
… and sometimes more complex wells



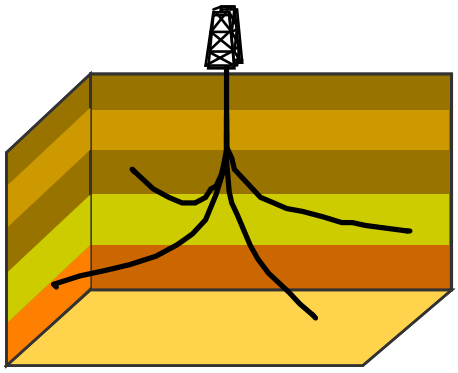
Stacked multibranch well



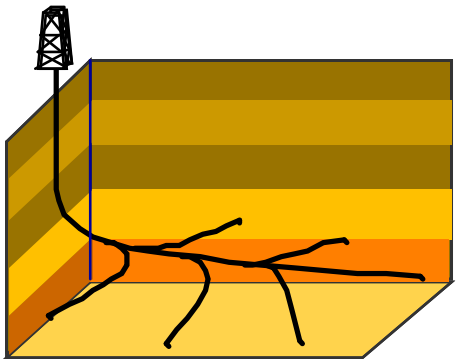
Dual opposing laterals



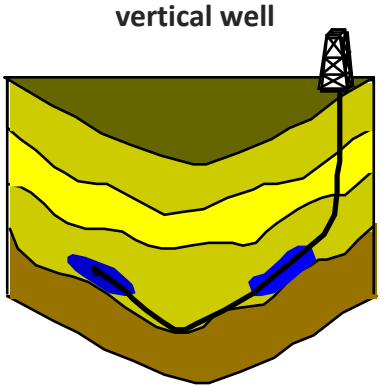
Re-entry laterals from a vertical well



Cluster well



Multidrain or multilateral well

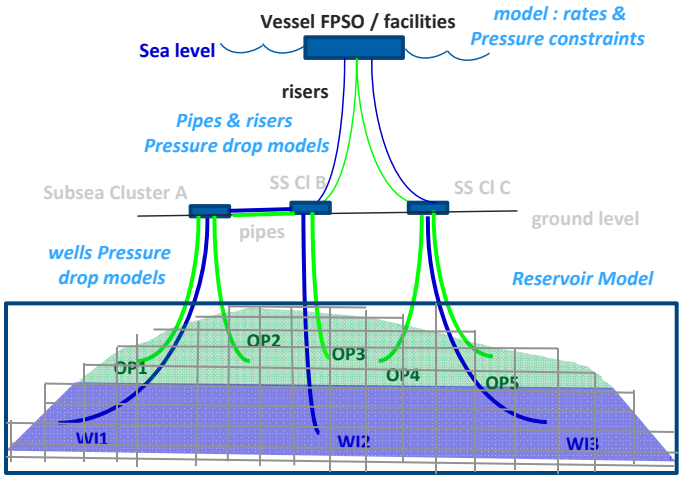


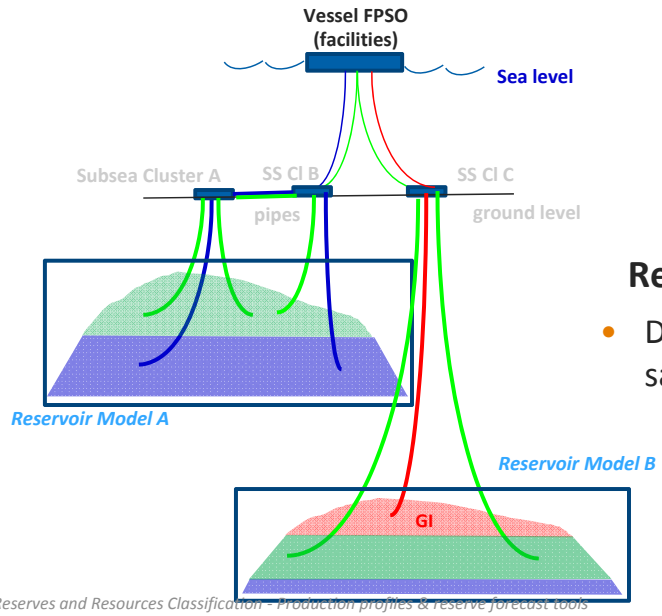
3D Well

Network / Reservoir coupling

Network

- Reservoir gridded
- Wells till Surface / subsea cluster
- Subsea pipe / riser network
- Surface facilities (capacities)





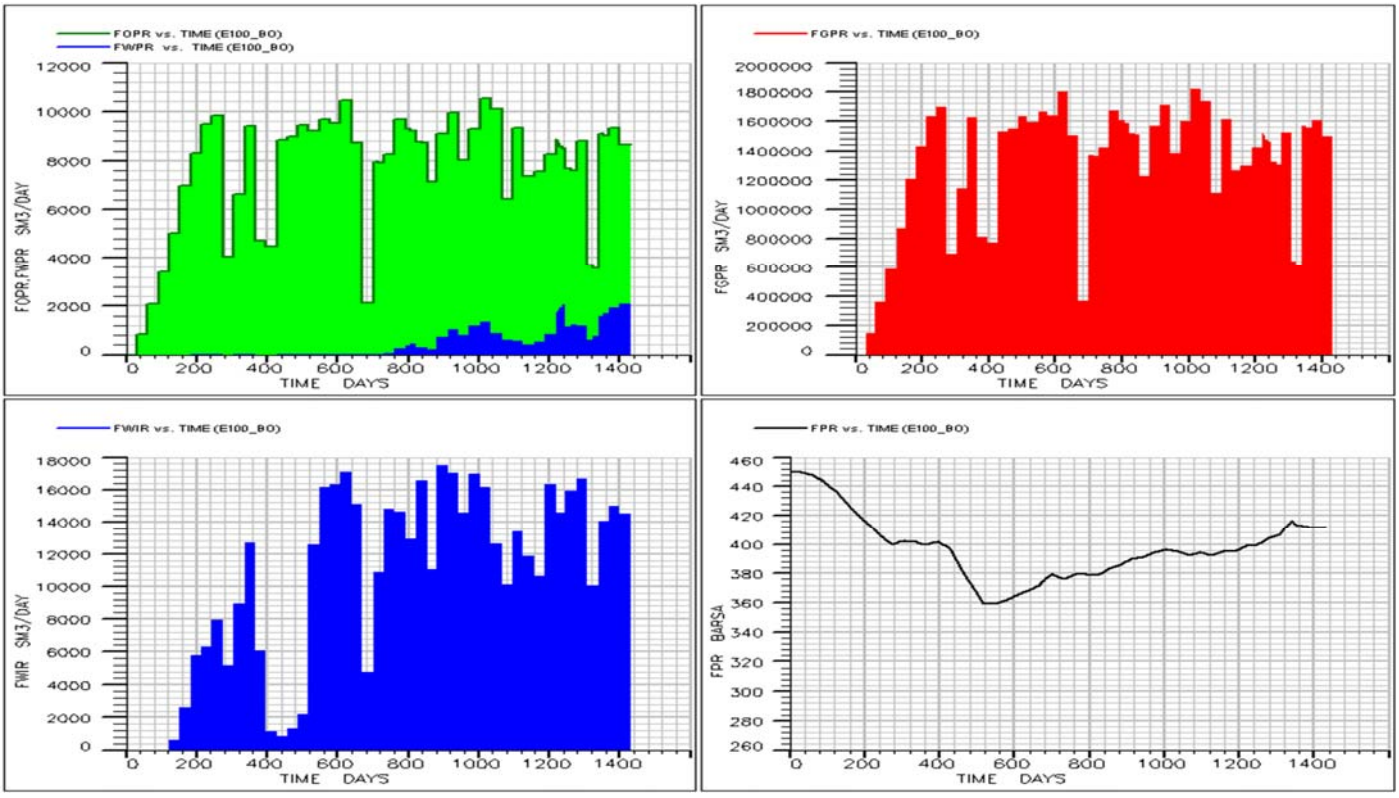
Reservoir coupling

- Different field reservoirs operated on the same surface facilities (& constrained)

Numerical models: spatial & time discretization

- **Spatial discretization**
  - Grid geometry (sugar box, corner point…)
  - Grid definition and cells dimensions
  - One value per grid for each data
  - Calculation of flow transfers between cells / Compressibility
- **Time discretization**
  - Time step definition
  - Calculation of production data per time step. Permeability
    - Data at the beginning of the time step = explicit schema
    - Data at the end of the time step = implicit schema
  - Calculation of the reservoir data at the end of the time step taking constant production data into account and constant reservoir data during the time step

Alwyn example: input time discretization



Basic data time step for input: # 1 month

For forecasts generally more: very often 3 to 6 months

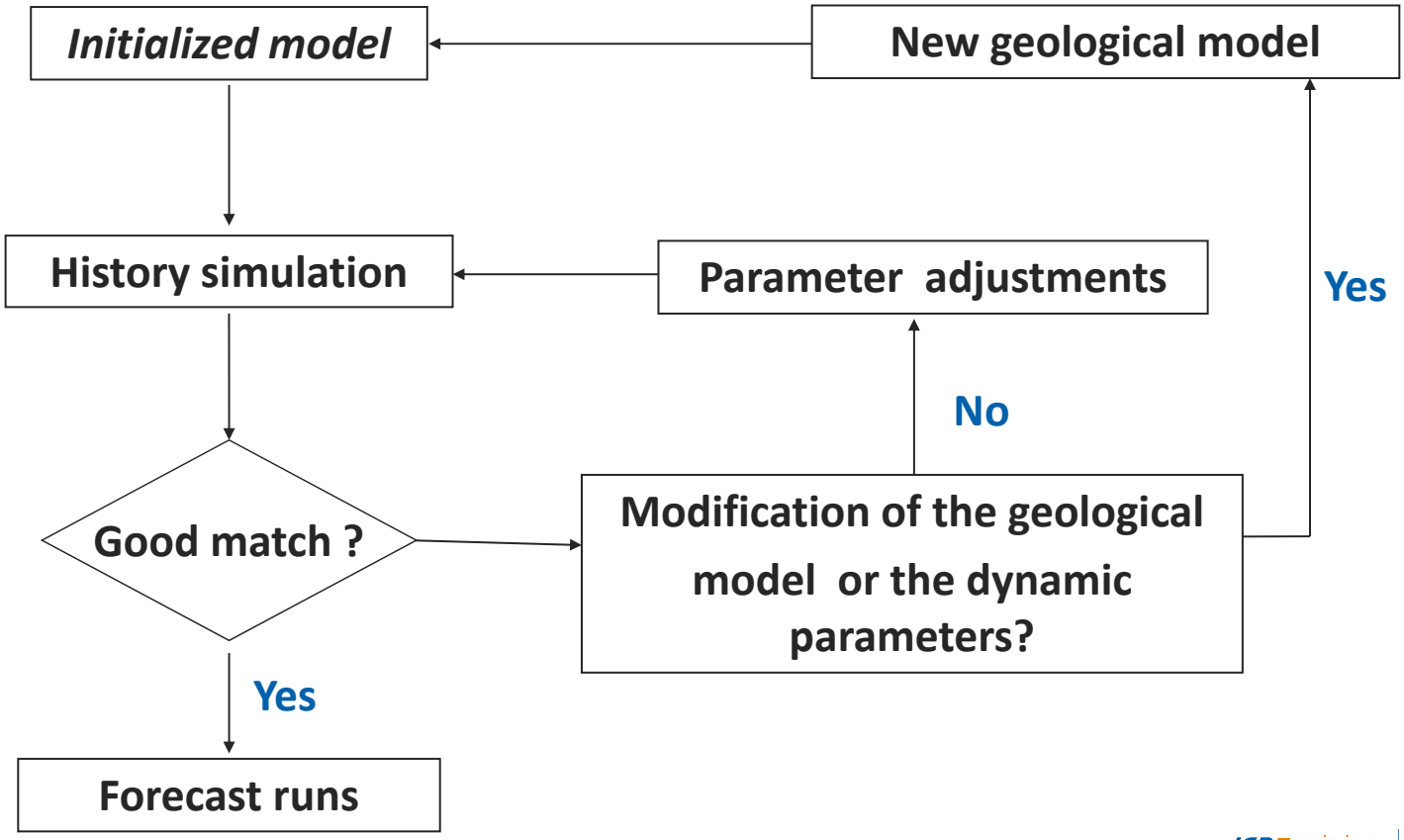
Reservoir simulation strategy & planning

- **Reservoir simulation study duration: from several weeks to years (updates & release) – daily use now in subsidiaries**
- **Necessity to carefully plan the study to give correct results in time, before to make decisions for the field management:**
  - Implication as early as possible of ResEng in the global GSR process
  - Preparation: Problem definition (identify issues / determine objectives / type of model to use)
  - Data review (available / interpretation / ..)
  - Data acquisition (to complete previous & improve modelling)
  - Reservoir characterization – Build geological static model
  - Upscaling to generate a dynamic reservoir simulation model
  - Dynamic model: Computing support
  - Initialization
  - History matching
  - Forecast
  - Reporting

History match

- **Objective: to reproduce with the model the real field history**
  - Well data to reproduce:
    - Pressure evolutions
    - Oil, gas, water productions
  - Field data to reproduce:
    - GOC / WOC contact displacements
    - Fluid fronts (Gas/Water) - 4D Seismic
- **Two main types of problems:**
  - Pressure match (field then wells) – diffusion effects
  - Saturation match (Water then gas) and associated productions at wells (O/G/W) – transfer effects
- **Overall methodology**
  - Identification of the matching parameters
  - Modification step by step of these parameters in case of mismatch
- **This is not a simple work as:**
  - Many GSR data are unknown (no information is available far from wells)
  - All data act together
  - There may be uncertainties on production / rate data (allocations, metering, ..)
  - Some artefacts must be corrected (grid size, grid orientation,…)

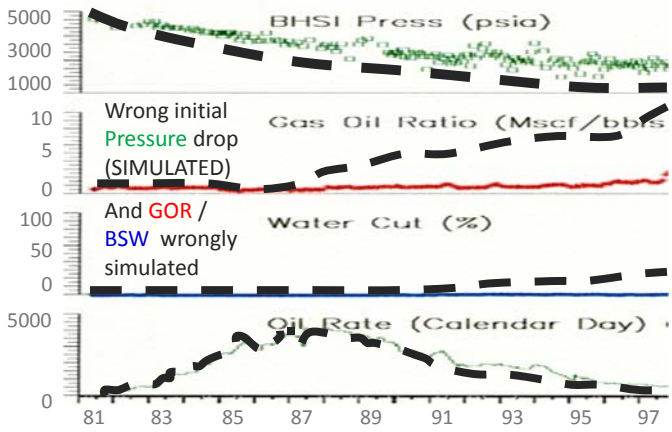
History match – Principle scheme



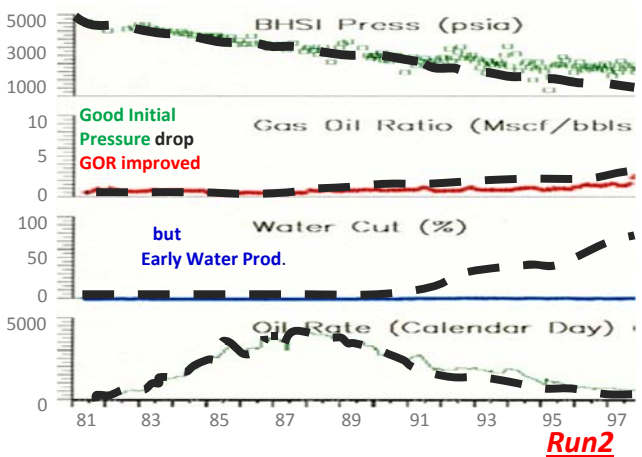
History matching: production data checking

- **Metering / Allocations**
  - Which metering: separator (Gas-Liquid, 3-phase separator), MPFM, …
  - Producers / injectors
  - Frequency of measurements (weekly, monthly?)
  - Activity factor (% of activity of the wells)
- **Detailed allocation for wells / multi-perforation**
  - Completion and well status (casing, cement) to be known
  - Production logging is the best tool to allocate rate
  - If no production logging, estimate the accuracy of allocation to intervals
  - When possible, draw the maps of the injected fluid breakthrough for each interval
- **Evolution of the fluid contacts and fronts:**
  - Use of saturation logging
  - Use of 4D-seismic when available (very powerful tool)

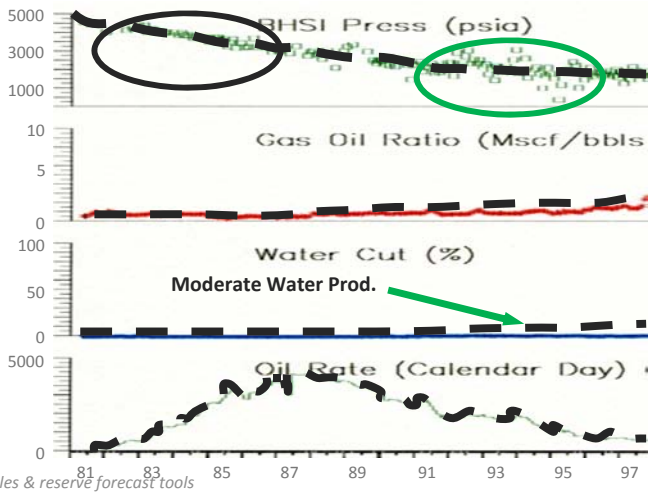
Example: general field match



Run1
Initial data



Run2
Aquifer activity increased



Run3
Oil permeability increase

- **Dynamic reservoir models are now widely used, primarily because they can solve problems that cannot be solved by other means.**
- **A reservoir model is a mathematical representation or translation of the image that geoscientists and reservoir engineers have of a reservoir**
- **Numerical simulations allow reservoir engineers to understand processes that are in action in the reservoirs and to predict reservoir behavior under various production scenarios**
- **Human factor is therefore an important aspect of reservoir simulation:**
  - A potential risk would be that users could consider their results as “representing the reality”…
  - Users’ experience is therefore an essential aspect in reservoir simulation



Data acquisition and monitoring

Data acquisition / monitoring : what for?

- **To prepare the development / exploitation strategy**
- **To reduce uncertainties / To build and calibrate models**
- **To prepare the future (reference monitoring)**
  - Extra development(s)
  - Secondary and tertiary actions (IOR and EOR)
- **And to optimize the short term (day to day monitoring)**
  - Well intervention / work overs
  - Adjust exploitation parameters

From knowledge to value

Data acquisition and monitoring

Outlines

1. **Introduction**
2. **Well data acquisition introduction**
3. **Global field acquisition - example**
4. **Reservoir monitoring at wells**
   1. While drilling
   2. Open Hole
   3. Cased Hole monitoring
5. **Reservoir monitoring testing / Field operations measurements**
6. **Reservoir monitoring / 4D seismic**
7. **Wells & monitoring costs examples**
8. **Examples of development updates & conclusion**

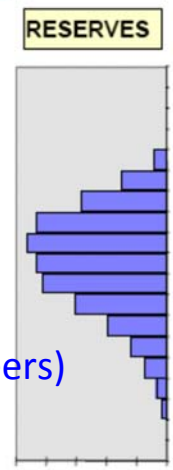
Data acquisition and monitoring

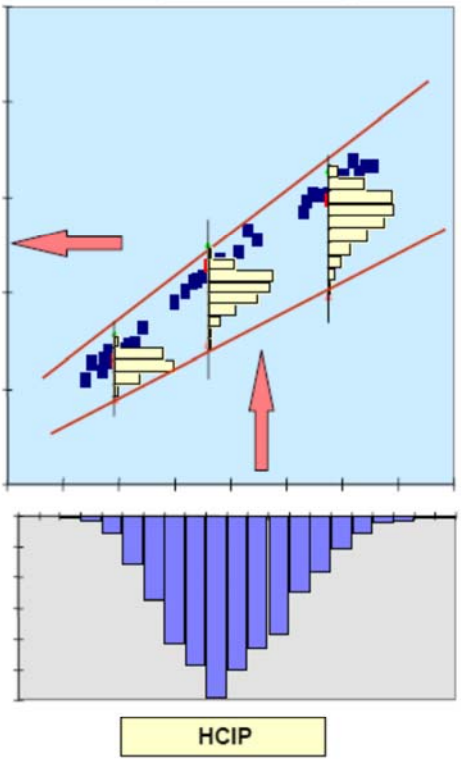
1. Introduction

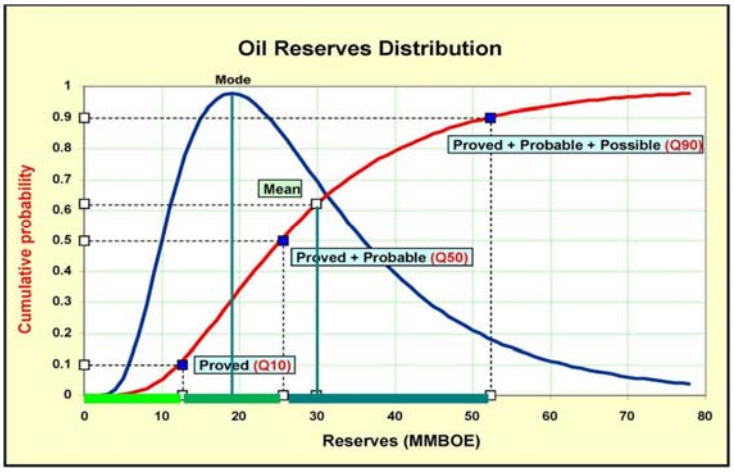
Reserves global workflow

- **Static uncertainties: HCIP distribution**
- **Combine static and dynamic uncertainties**
- **Reserves distribution**
  - Integrated process with GSR staffs

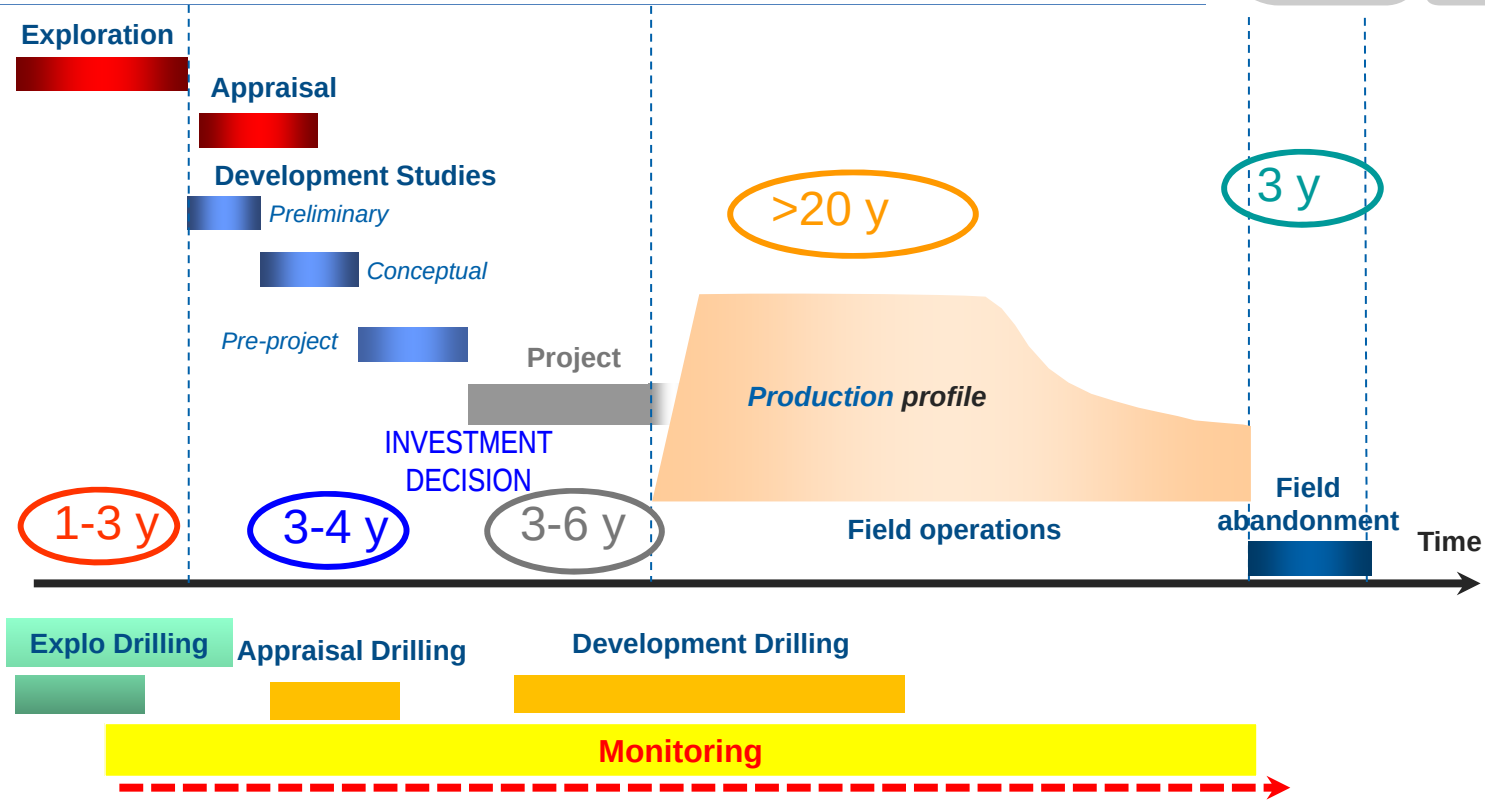
(Geophysicists / Geologists / Reservoir Engineers)







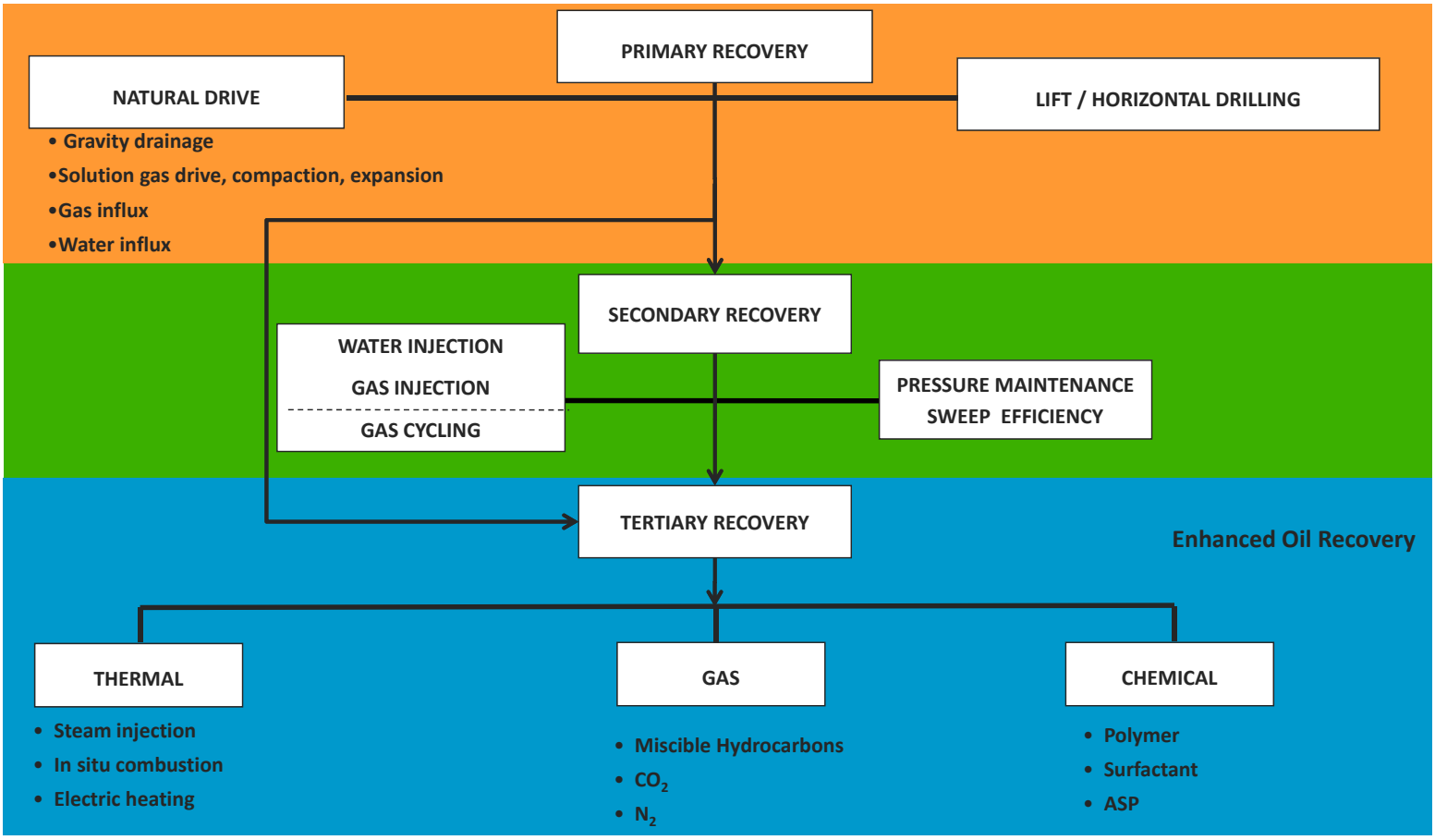
Monitoring when?



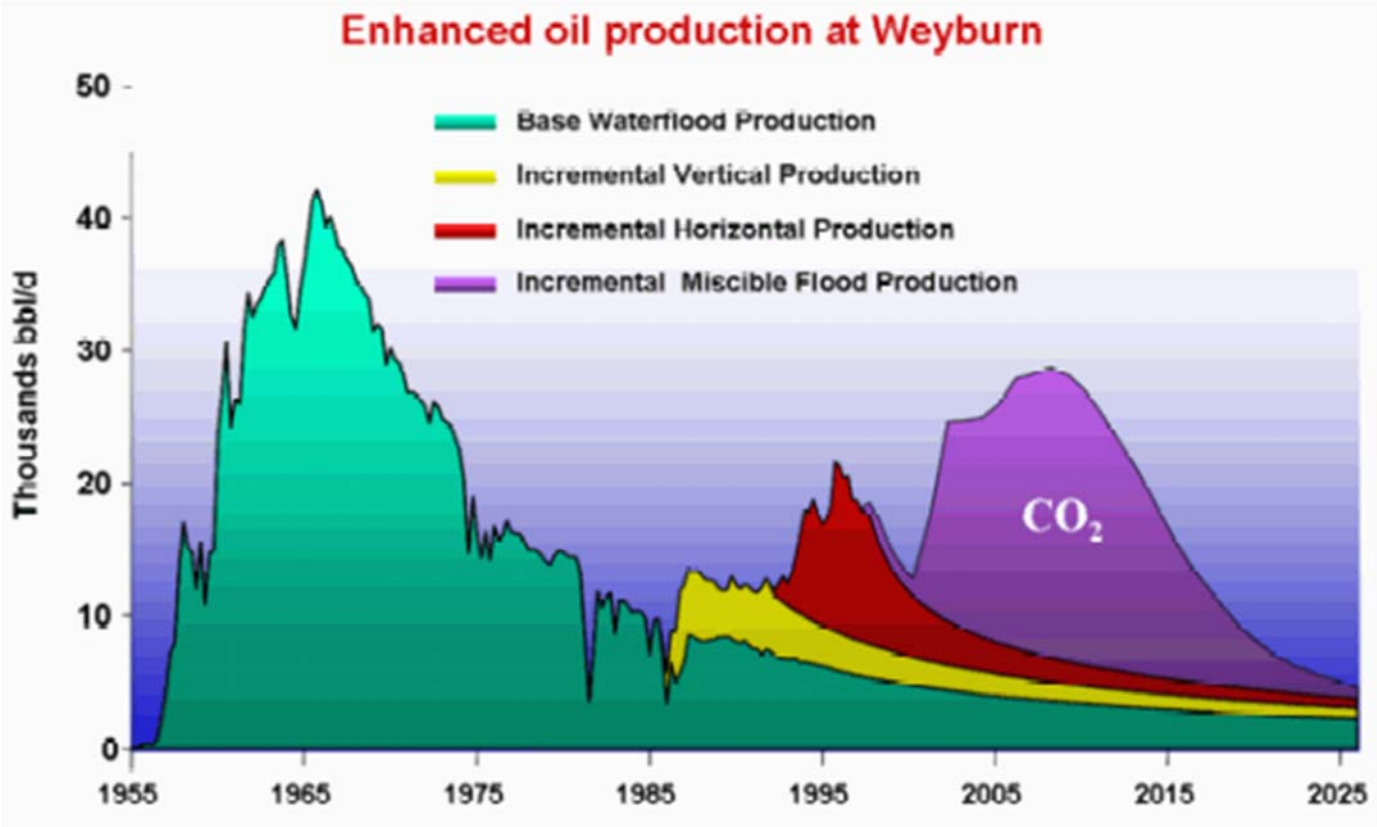
All the measurements performed during the field life

As time goes on, from the comparison with the previous or initial measurements (baseline), these measurements provide us with valuable information on the reservoir behavior

Reservoir drive mechanisms



Reservoir monitoring and drive mechanisms



Monitoring acquisitions vs different phases

- **Exploration phase**
  - Seismic
  - Surface geology / outcrops-analogies
  - Well data (logs, cores, Well Tests, PVT, pressures)
- **Appraisal phase**
  - Well data (Logs, cores, Well Tests / interferences, PVT, pressures)
  - Seismic HD (base line 4D?)
- **Development phase (RMP and RmP)**
  - Before start of production: (RMP)
    - Well data (Logs, cores, Well Tests BU & FO / interferences, PVT, pressures)
  - After start of production (Update of reservoir monitoring plan)
    - Well data (Logs, pressures, sampling)
    - Classical well & field monitoring (tests, production/saturation logging, metering, PVT…) – punctual/permanent devices
    - Field scale monitoring : 4D seismic



Data acquisition and monitoring

2. Well data acquisition introduction

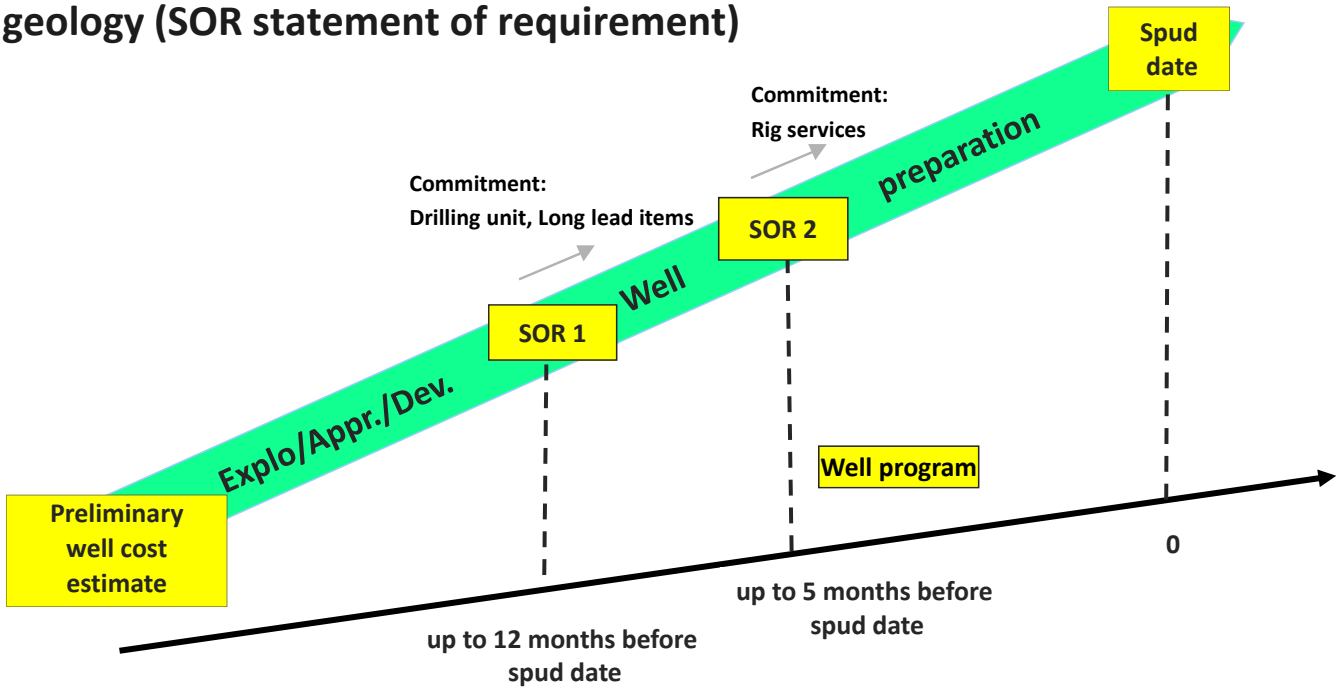
Monitoring

Data acquisition associated with wells

- Drilling / Mud logging
- Drilling / Coring
- Open hole logging (MWD, LWD, Wireline logs)
- (Cased hole) well / Cementation logs
- (OH & CH) well / Well seismic profiles
- Completed well (initial & FO) / Testing
- Completed well (initial & FO) / Production logging & Saturation logging
- FO well / Production parameters (rates, fluids, ..), fluids analysis (salt, chemicals, …)

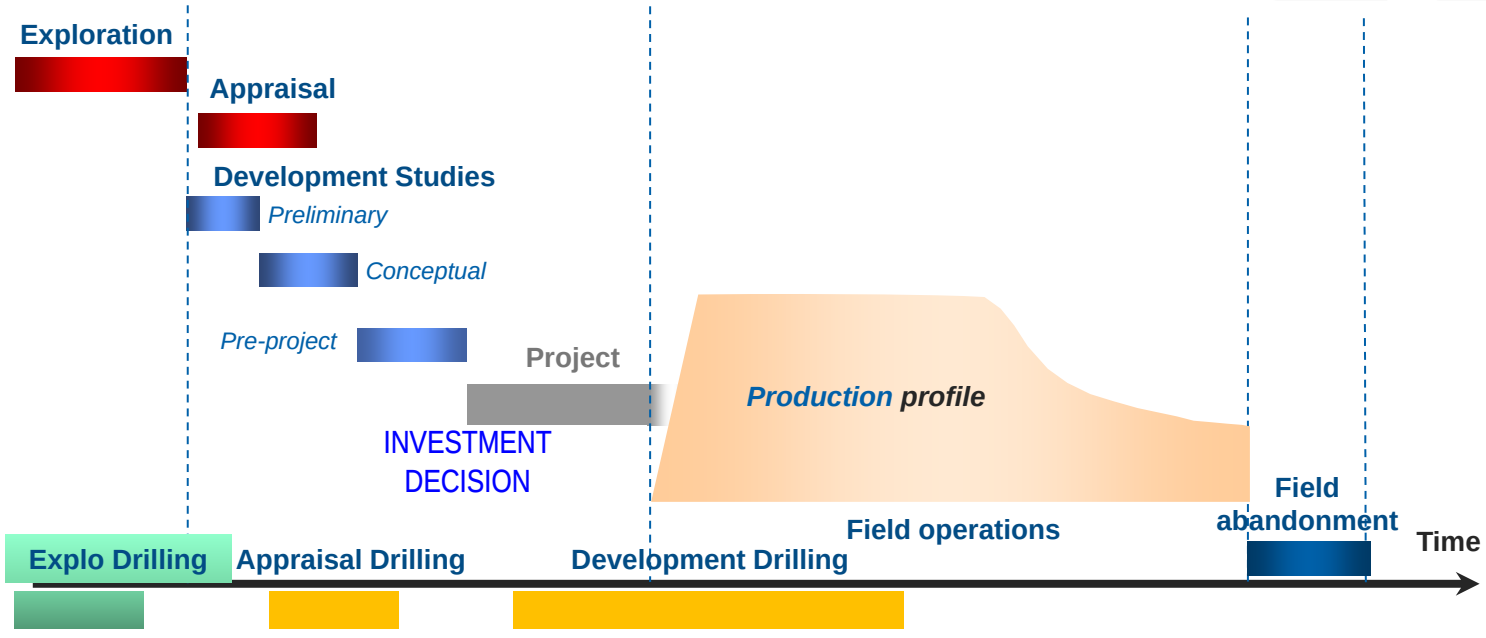
Monitoring at well realization / preparation process

- A **permanent process** under the joint responsibility of drilling and operational geology (SOR statement of requirement)



  - … and preparation/**anticipation** on necessary acquisition vs necessary needs

Monitoring - Oil & Gas field development phases



- **Anticipation** during preliminary/conceptual studies on devices to be planned for monitoring during the production period
  - "GSR" permanent devices: P/T Bottom Hole (gauges, optical fiber),
  - "FO" permanent devices for metering (Downhole MPFM, ..)
  - Well completion: smart completion, isolation devices, …



Data acquisition and monitoring

3. Global field acquisition examples

Successive stages of production

Gathering,

Treatment,

Storage,

Metering,

Export

- **Treating produced fluids :**
  - **Allows their export**
  - **While maximizing production**
  - **In respect of contractual specifications**
- **Such treatments should be performed :**
  - **In a cost-conscious way**
  - **With respect to safety and environment**

Objectives of crude oil & gas field processing



TO COLLECT AND TREAT WELL EFFLUENTS in a SAFE WAY
TO OBTAIN TRANSPORTABLE and/or SALEABLE FLUIDS
natural gas, condensate, crude oil

TO OPTIMIZE RECOVERY OF HYDROCARBONS PRESENT IN RESERVOIRS
by injection of water and/or gas in the reservoirs

TO DISPOSE OF UNDESIRABLE COMPONENTS SAFELY AND WITHOUT HARMING THE ENVIRONMENT
- ***Liquid water or brine present in reservoirs and entrained to the surface by crude oil or natural gas (PRODUCED WATER)***
- ***Associated gases or gases released in emergency situations or process upsets (use of a FLARE)***

Components of well effluents

- **Inert gas: Nitrogen, Helium**
- **Acid gas:**
  - H2S: Hydrogen sulphur, extremely corrosive and deadly
  - CO2: Carbon dioxide, corrosive
- **Hydrocarbons:**
  - Light: C1 C2 C3 C4
  - Heavy: C5 . C6 . C7 … C10 ... C30 ...
  - (Paraffin, Naphtene, Aromatics, …)
  - Sulphur (mercaptans)
  - Nitrogen, Oxygen
  - Organo-metallic (Asphaltene)
- **Water & Salt**
- **Solids : Sand, Clay, Corrosion products ...**

Export specifications examples

- Crude oil:
  - Volatility : vapor pressure (Reid vapor pressure)
  - Max content H_2S (ppm weight)
  - Max content water + sediments (BSW)
  - Salinity max (mg/l of salt)

Examples

- **10 psi (RVP max.)**
- **40 ppm**
- **0.2 % max.**
- **60 mg/l**

- Gas:
  - HC condensation (Dew point HC)
  - Water condensation (Dew point water)
  - Max content H2S (ppm)
  - Max content CO2 (%)
  - Wobbe Index (GHV/d^0,5)

Examples

- **- 7 °C @ 70 bar a**
- **- 15 °C @ 70 bar a**
- **10 ppm vol**
- **2.5 % vol**
- **40 - 43 MJ/Sm3**

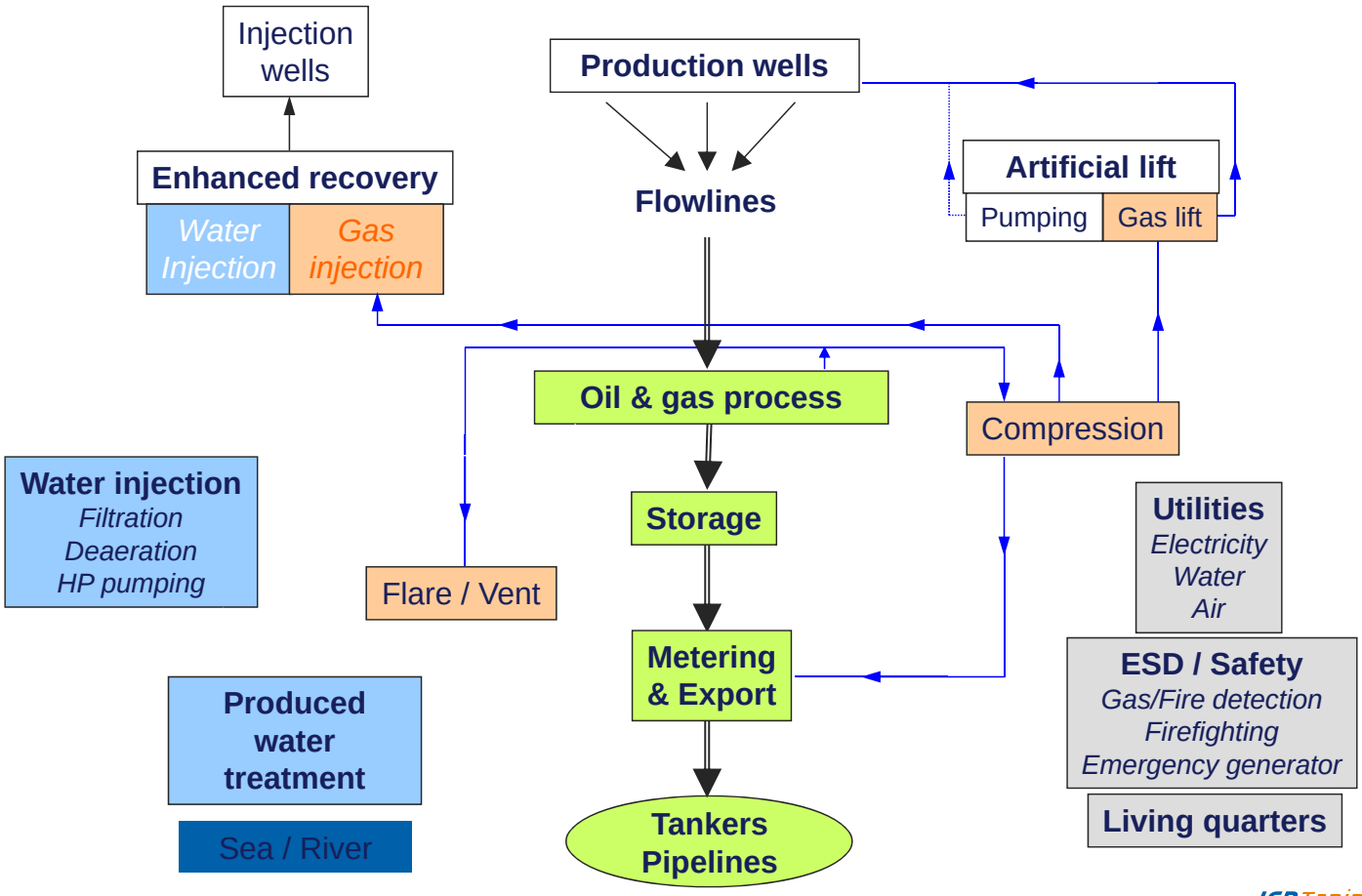
Examples of Oil & Gas facilities



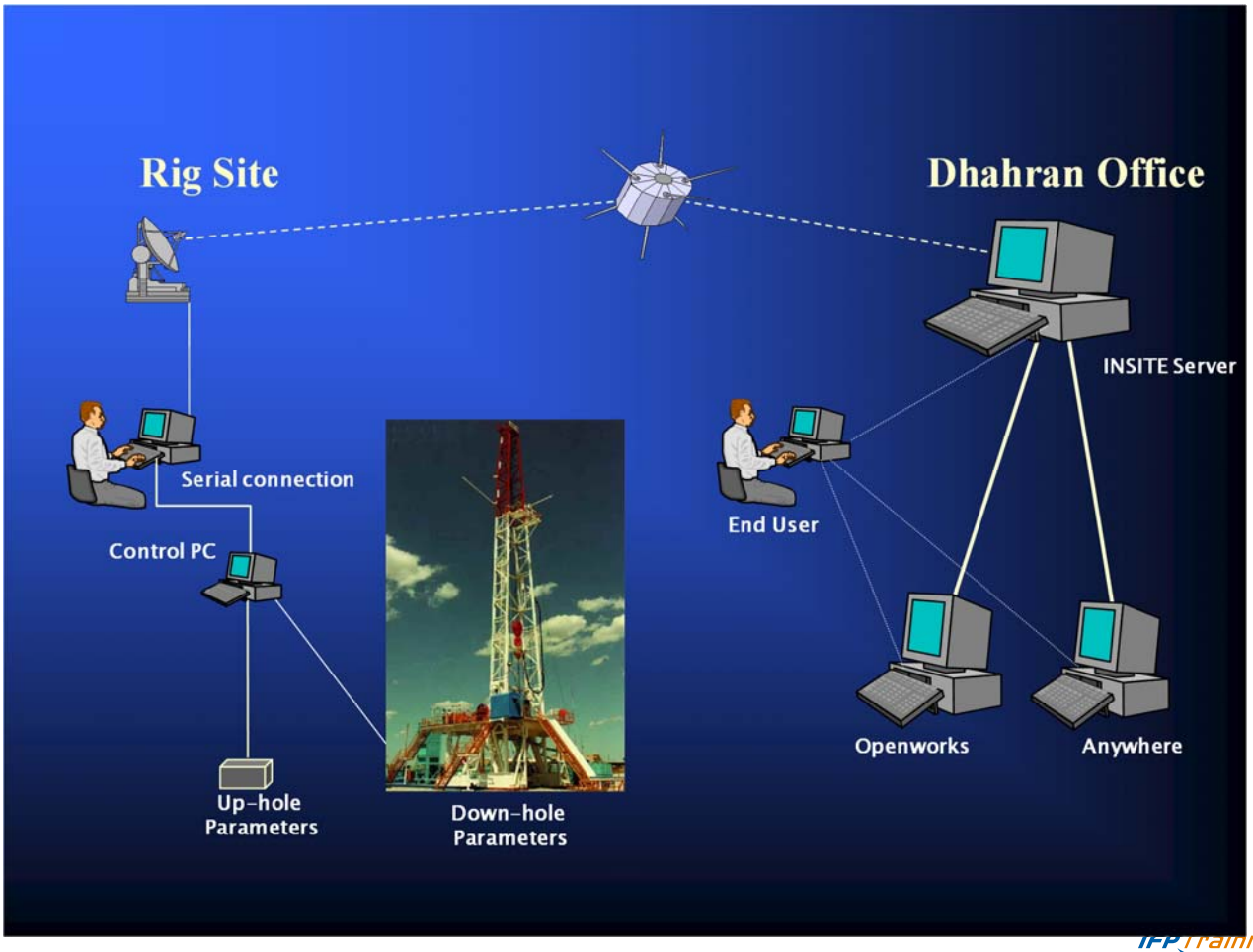




Producing field functional diagram (example)



Real time drilling monitoring and reservoir navigation



Ghawar field

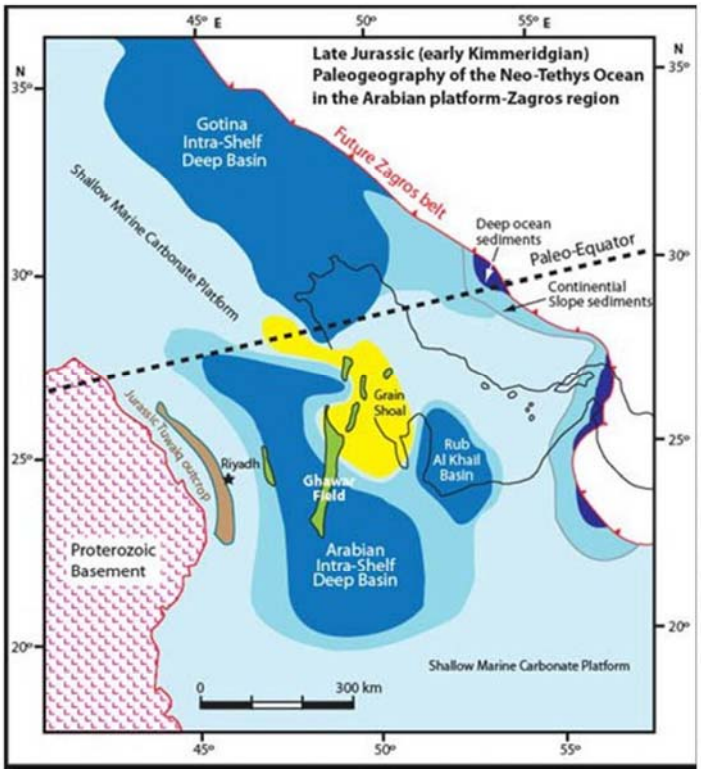


Table 2. Arab-D reservoir in the Ghawar field (north to south)

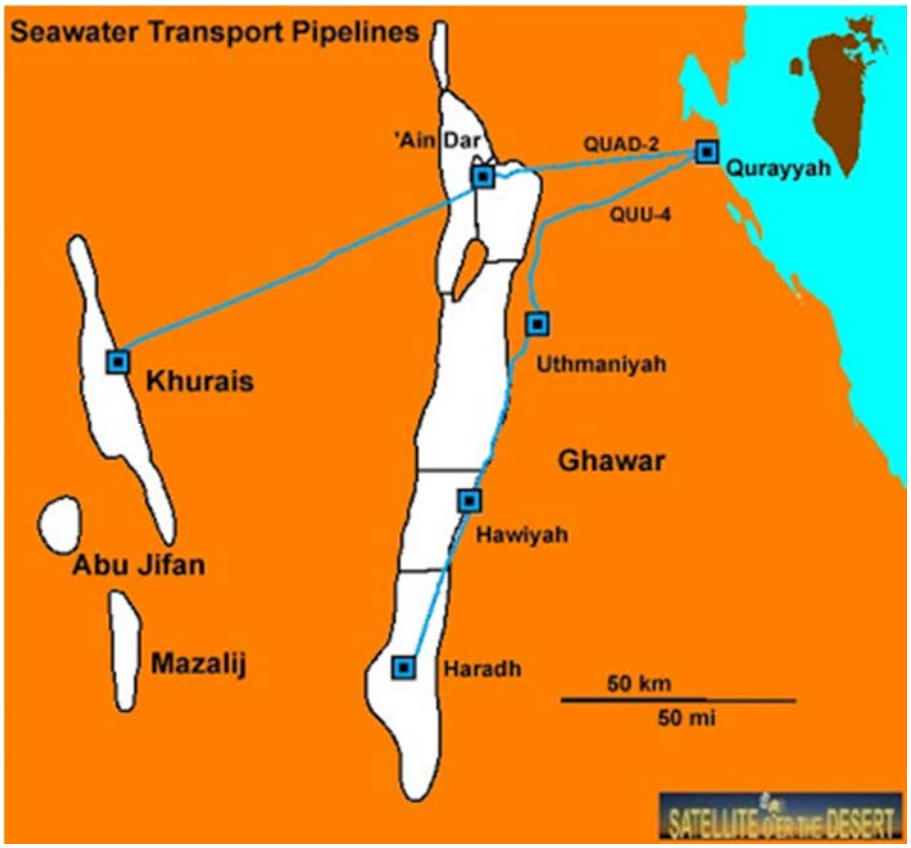
	Ain Dar	Shedgum	Uthmaniyah	Hawiyah	Haradh
Oil-water contact depth (ft)	6430 to 6665	6444 to 6689	6347 to 6570	6152 to 6576	6000 to 6620
Net thickness (ft)	204	194	180	180	140
Formation volume factor (RB/STB)	1.34	1.35	1.31	1.30	1.27
Initial solution gas-oil ratio (SCF/Bbl)	550	540	515	485	470
Oil gravity (API)	34	34	33	32	32
Reservoir oil viscosity (centipoise)	0.62	0.62	0.73	0.85	0.89
Sulfur (weight %)	1.66	1.75	1.91	2.13	2.15
Porosity (%)	19	19	18	17	14
Permeability (mD)	617	639	220	68	52
Water saturation (%)	11	11	11	11	11
Productivity index (oil volume/pressure) (bopd/psi)	141	138	92	45	31

Data source: *Saudi Aramco Oil Reserves, Table of Basic Data, Year-end 1980* (quoted in "The Ghawar Oil Field," Greg Croft Company)

Discovered in 1948 and put on stream in 1951

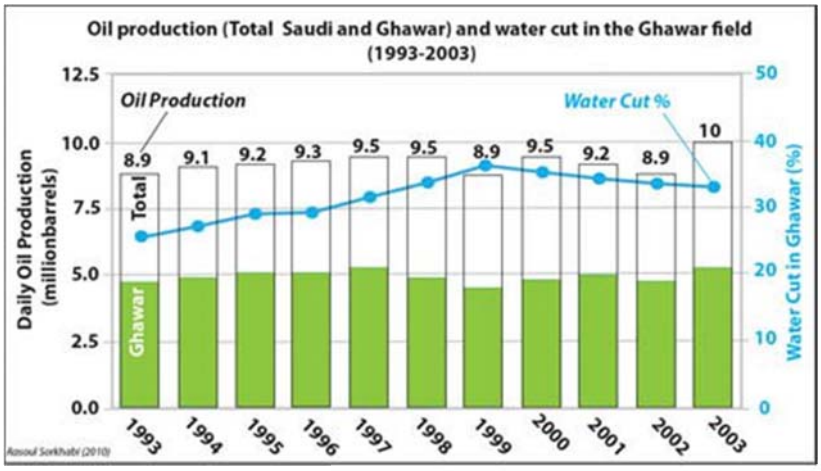
Ghawar field



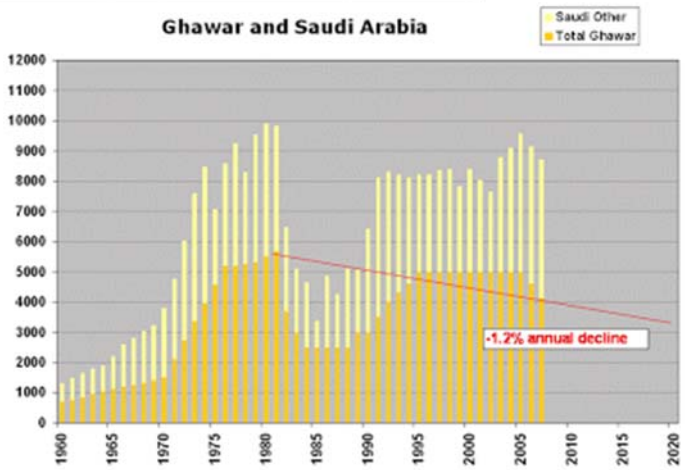


http://satelliteoerthedesert.blogspot.fr/2008/01/how-many-wells-in-ghawar.html

Ghawar field



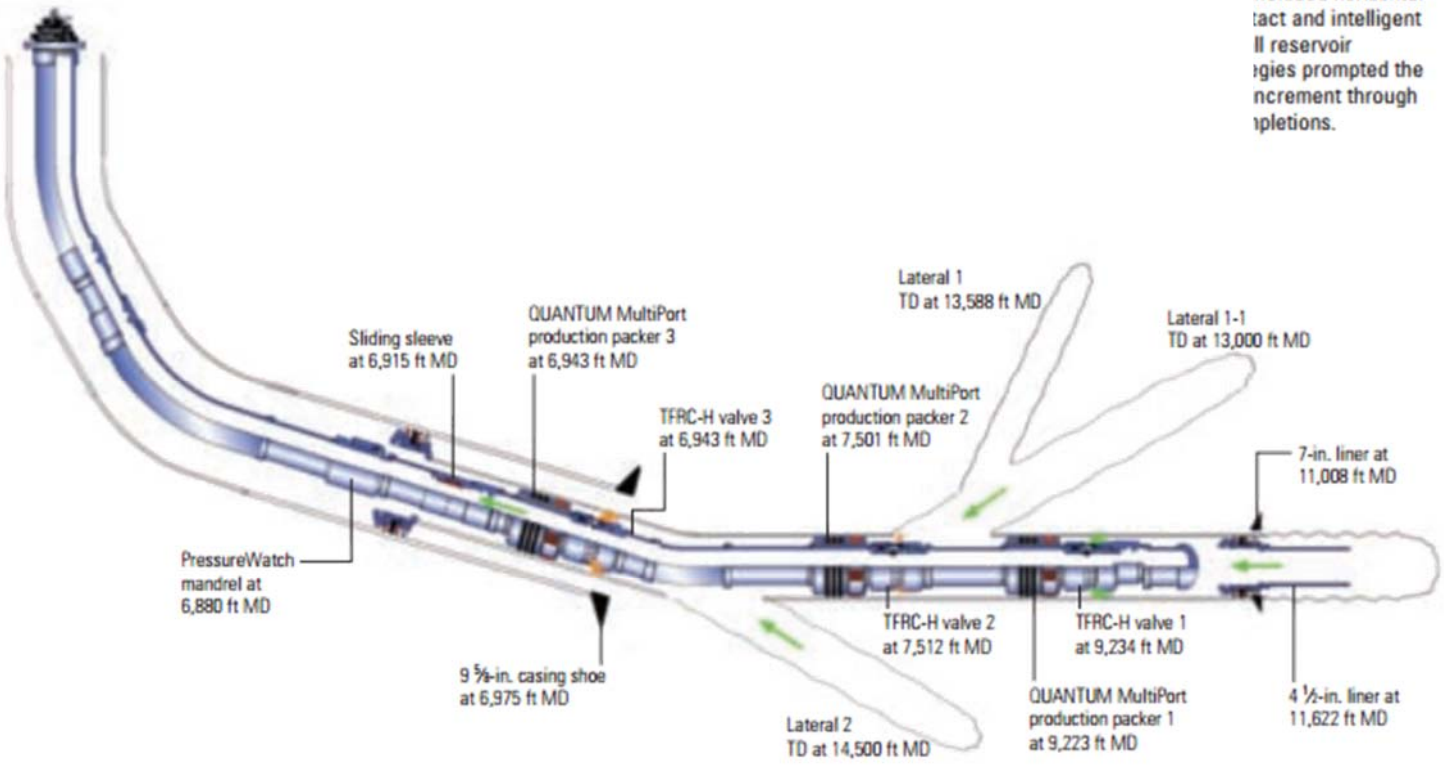
http://satelliteoerthedesert.blogspot.fr/2008/01/how-many-wells-in-ghawar.html



Inflow control valves (ICV)

Inflow control device (ICD)

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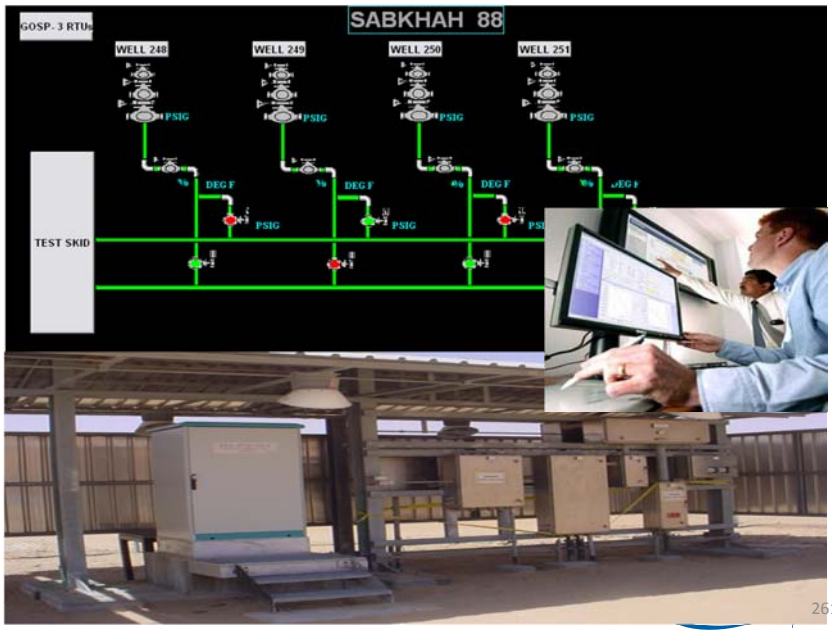


Shaybah plan



Objective:

- **Real Time Decision**
  - Production optimization
  - Better reservoir management



Shaybah field

- **Automating the calculation of individual well production rates using real-time pressure data from permanent sensors installed on wells.**
- **This system has been implemented in a large Saudi Arabian field.**

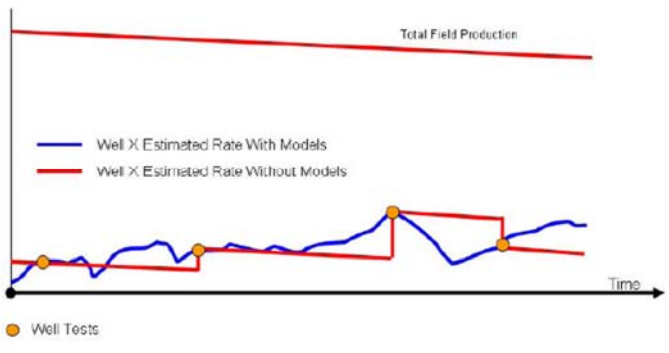


Figure 7: Comparison of well rate estimation with and without models

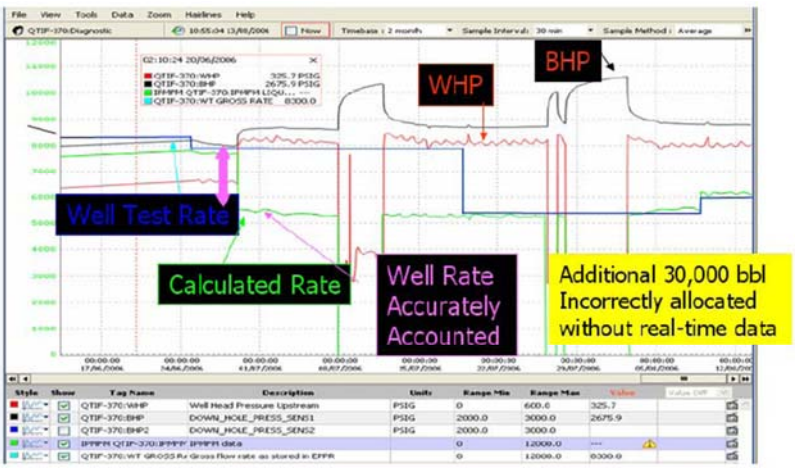


Figure 9: Proper well downtime accounting prevents misallocation of well production



Data acquisition and monitoring

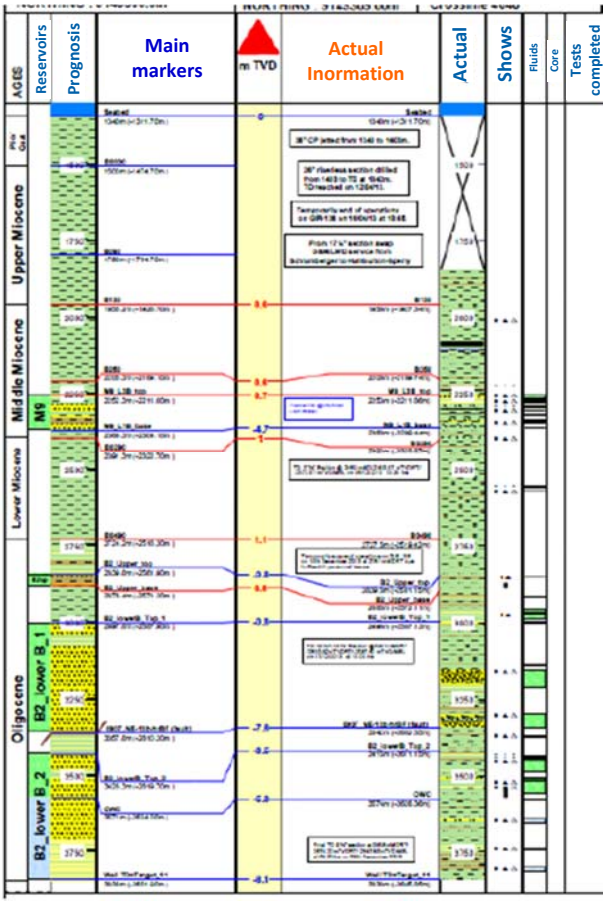
4. Reservoir monitoring at wells
    1. While drilling
    2. Open Hole
    3. Cased Hole

4. Reservoir Monitoring at wells

1. **Drilling**
    1. Mud logging
        1. Sedimentology/Mineralogy (cuttings)
        2. Fluids (gas shows)
    2. Coring
        1. Sedimentology
        2. Petrophysics: routine (Phi/K/Rho), SCAL (Kr, Pc), other-long cores miscibility studies, …
        3. Matching logs / cores (porosity)
        4. Matching / scaling logs/cores/well test (permeability)
2. **Open hole logging (MWD, LWD, Wireline/CT/TLC logs)**
    1. Petrophysics, saturation (fluids)
    2. Pressure (RFT,..), Fluids (MDT, sampling)
3. **Cased hole logging**
    1. Cement evaluation
    2. Saturation tools
    3. Production logging

Logging while drilling

- **Drilling / Mud logging example**
  - Sedimentology/mineralogy (cuttings)
  - Fluids (oil shows / gas analysis allowing vertical communication analysis)
- **Drilling / Coring**
  - Sedimentology
  - Petrophysics: routine (Phi/K/Rho), SCAL (Kr, Pc), other: long cores for microscopic recovery on 2ry, EOR studies (polymer, miscibility studies, …
  - Matching logs / cores (porosity)
  - Matching - upscaling logs/cores/well test (permeability)

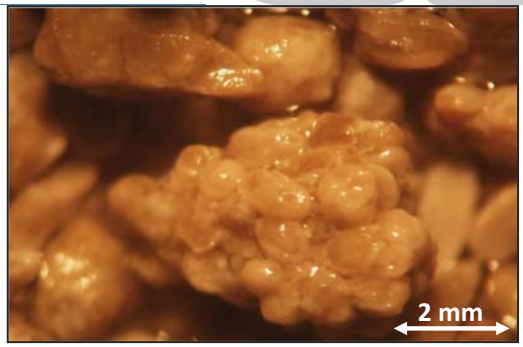


Catching samples & observation



Spot sample

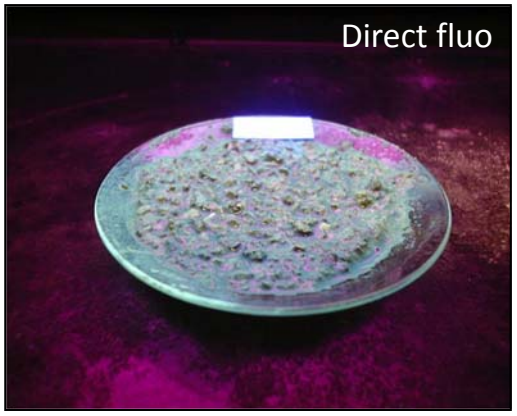
Sample interval

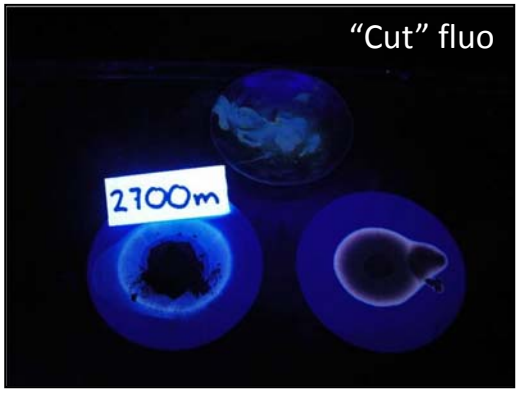




Oil shows detection

- **Direct or "cut" fluorescence**
  - Presence of hydrocarbons
  - Active (gas or liquids)
  - Fossil (bitumen or asphalt)
- **False fluorescence**
  - Drilling oil (lubrication)
  - Exhaust gas (engines)
  - Contaminated mud or equipment (tanks, pits,…)



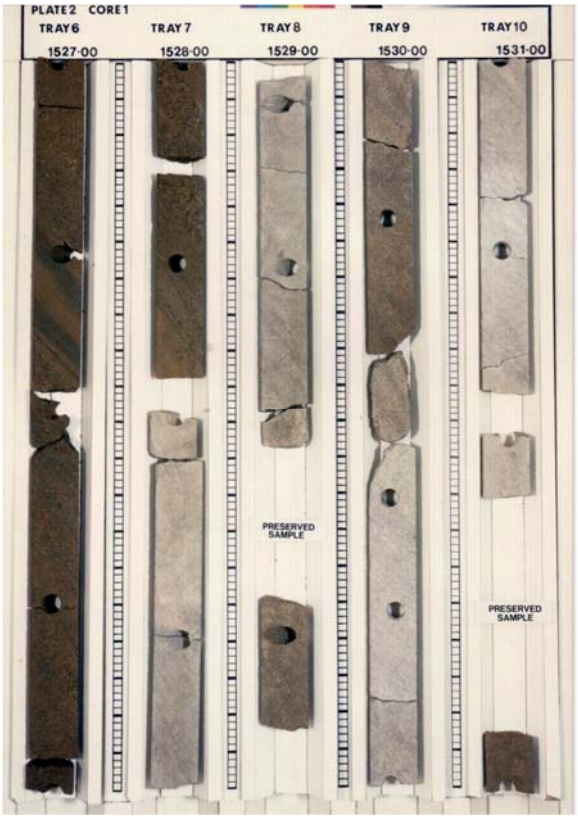




Rock sampling: cores & plugs



Core bit





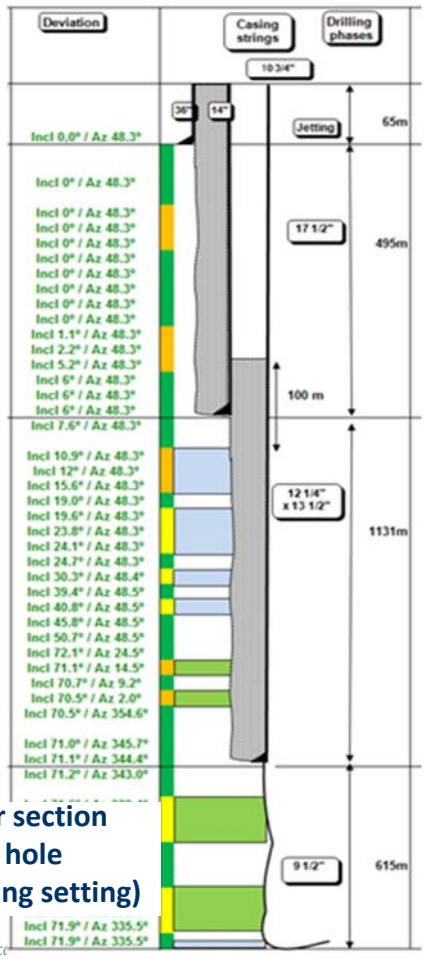
4. Reservoir monitoring at wells

1. Drilling
   1. Mud logging
      1. Sedimentology/mineralogy (cuttings)
      2. Fluids (gas shows)
   2. Coring
      1. Sedimentology
      2. Petrophysics: routine (Phi/K/Rho), SCAL (Kr, Pc), other-long cores miscibility studies, …
      3. Matching logs / cores (porosity)
      4. Matching / scaling logs/cores/well test (permeability)
2. **Open hole logging (MWD, LWD, Wireline/CT/TLC logs)**
   1. Petrophysics, saturation (fluids)
   2. Pressure (RFT,..), fluids (MDT, sampling)
3. Cased hole logging
   1. Cement evaluation
   2. Saturation tools
   3. Production logging

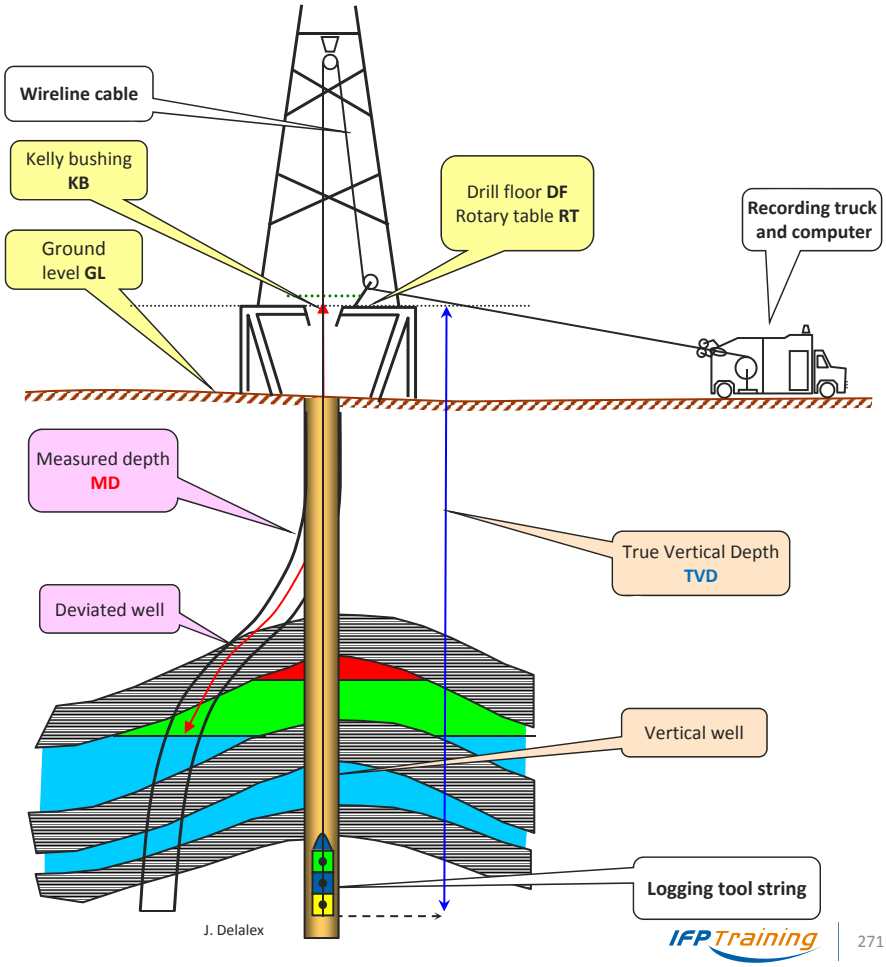
Open hole vs cased hole logs

- **Open hole logs**
  - It is the unique opportunity in the well lifetime to measure the ''initial'' formation properties
- Cased hole logs
  - To monitor the changes in the well and the formation properties during the well lifetime
  - Often, base logs are taken at time t=0. All the subsequent logs will reflect changes: time lapse technique

Onshore wireline logging



Reservoir section
Open hole
(before casing setting)

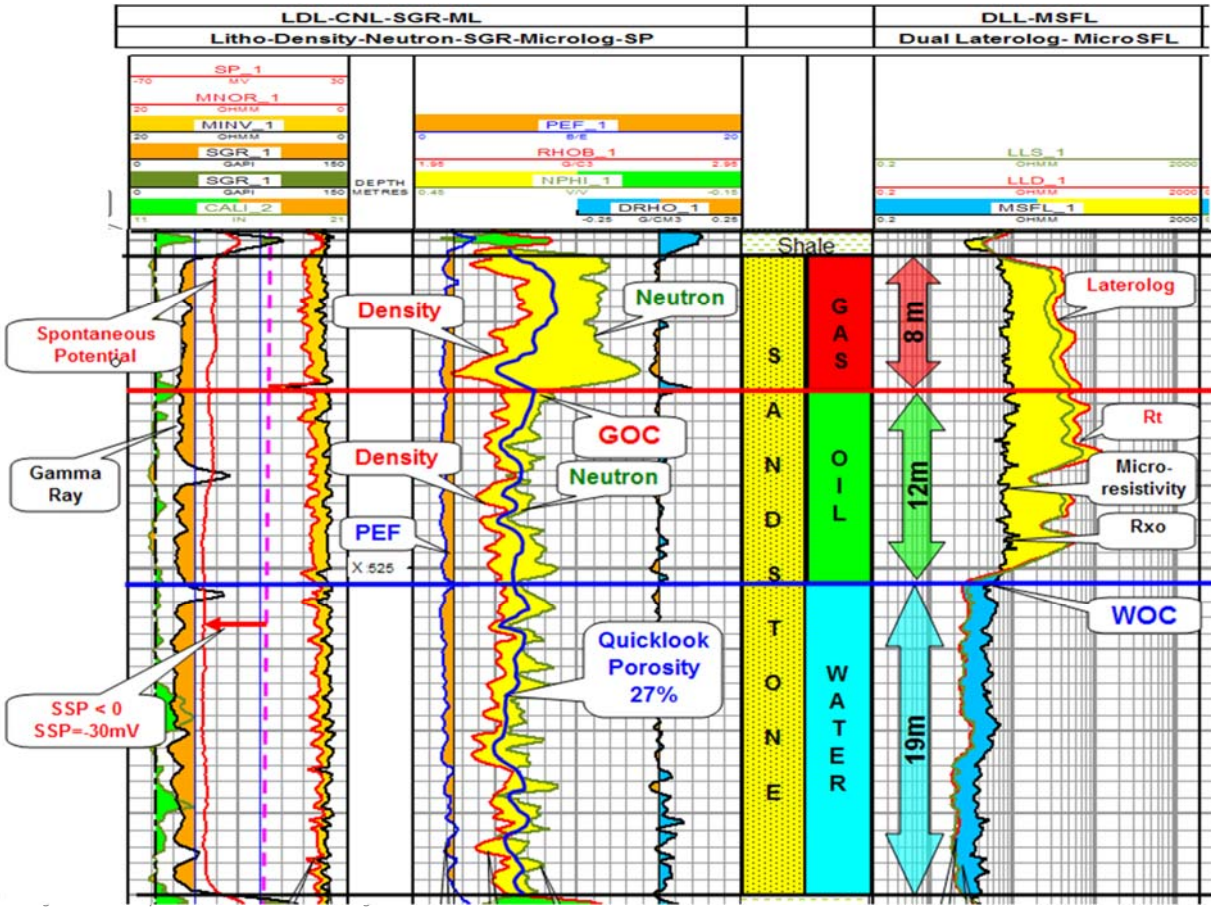


Types of wireline logging tools

- **Natural phenomena recording**
  - Well diameter — **Caliper**
  - Natural radioactivity — **Gamma Ray**
  - Formation temperature — **Temperature**
- **Artificially stimulated phenomena recording**
  - Formation resistivity — **Resistivity, Induction** → Fluid
  - Formation lithology & porosity — **Neutron, Density, Sonic** → Rock
- **Tools**
  - Source/receiver spacing
    - Depth of investigation
    - Vertical resolution
  - Centered in borehole or pressed against wellbore (pad)

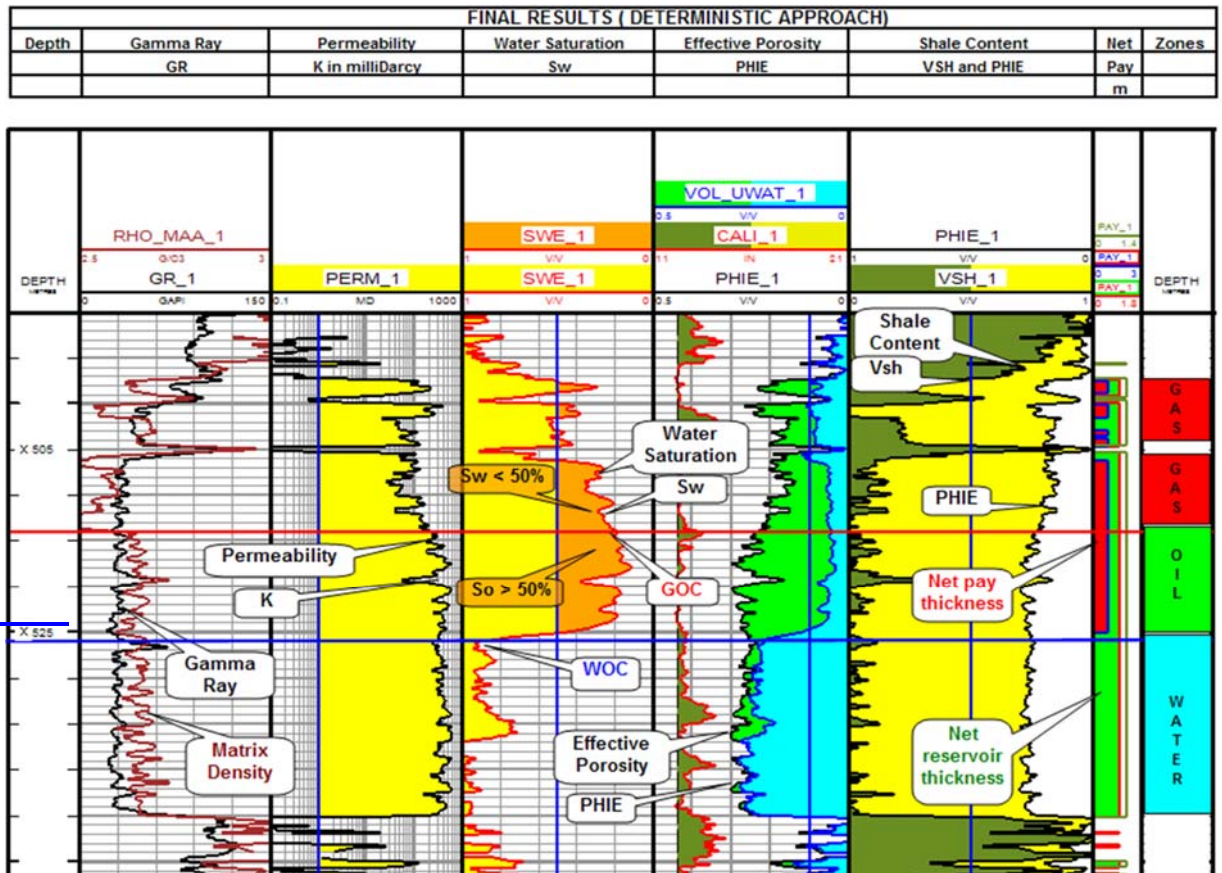
→ Determination of both reservoir zones and fluid content
- Invasion (mud cake detection)
- Identification of fluids and respective saturations

Typical interpretation of OH logs: fluid contacts, Lithology & porosity



Typical interpretation & log evaluation

Vsh, porosity, Sw, permeability



Oil Zone :

$$S_w = \sqrt[n]{\frac{aR_w}{\phi^m R_t}}$$

$$S_w = \sqrt[2]{\frac{0.81*0.18}{0.27^2*60}}$$

$$S_w = 18\%$$

$$S_o = 82\%$$

$$R_w = R_t \frac{\phi^m}{a}$$

$$R_w = 2x\frac{0.27^2}{0.81}$$

$$R_w = 0.18\text{Ohmm}$$

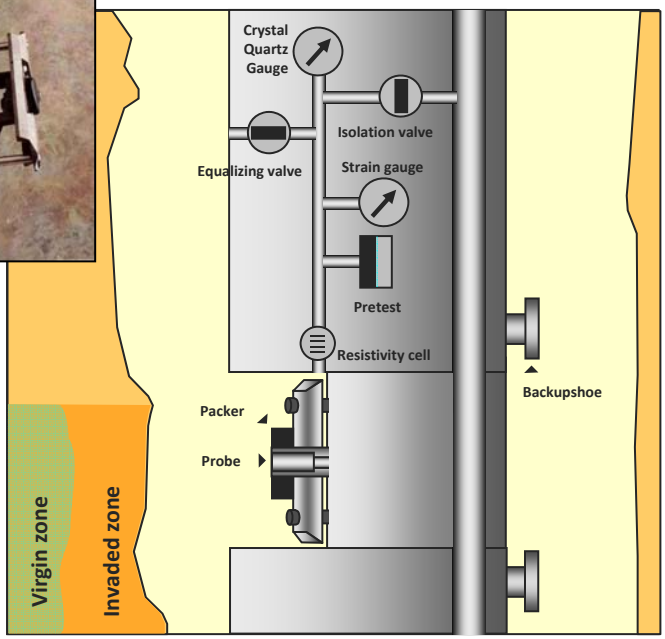
Oil zone : h = 10 m , Avg Phi = 27% , Avg So = 80 % => hPhiSo = 2.16 m

Fluid sampling and pressure gradient measurement

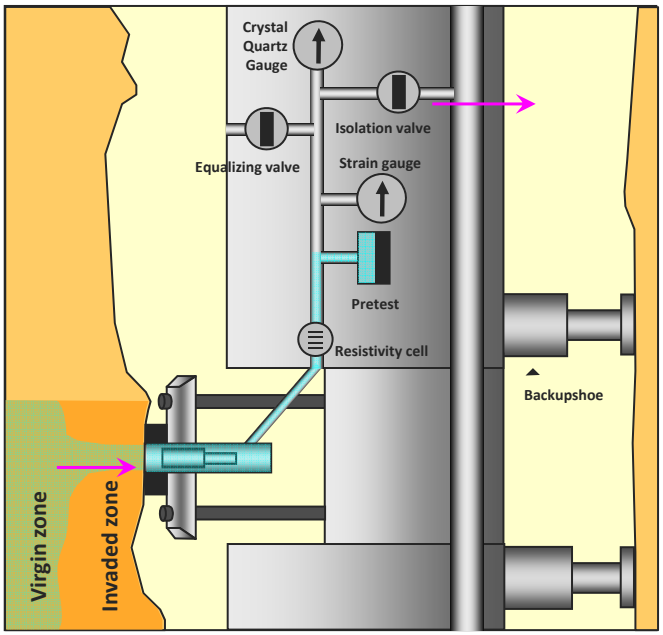


Modular Dynamic Formation Tester

MDT / RFT logging tool



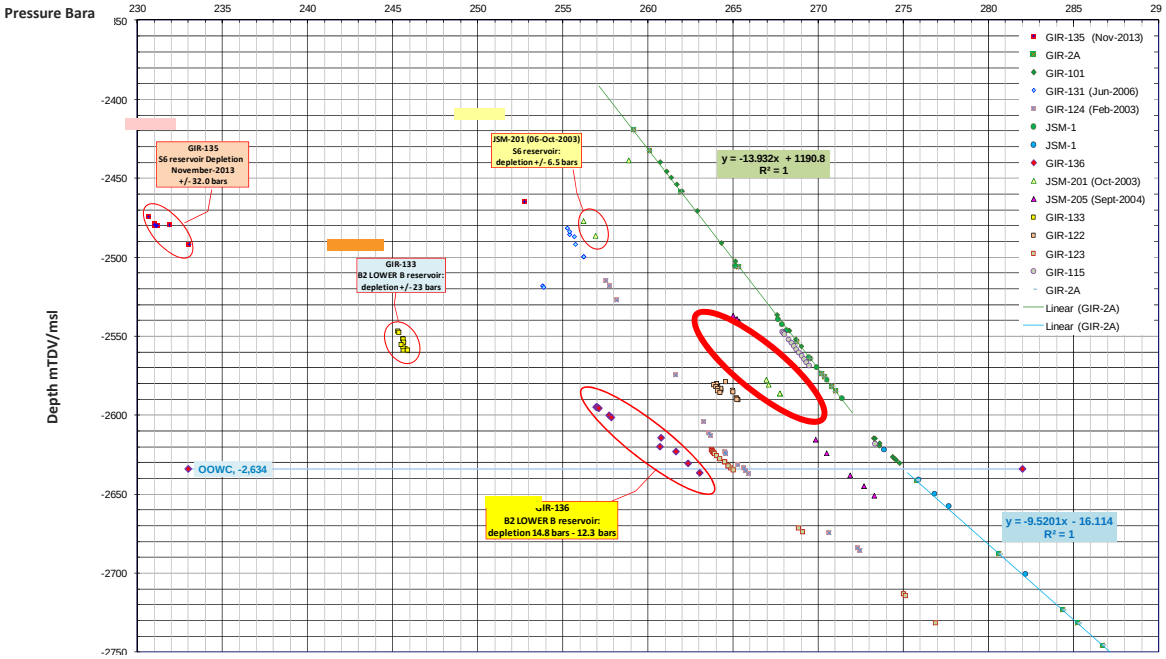
MDT: closed tool



MDT: open tool

… Other open hole acquisition & logs

- Wireline formation tester (WFT) or repeat formation tester (RFT) or XPT (new technology)
  - Measures the formation pressure
  - Allows fluid sampling and "relative" permeability of the formation



- Well seismic acquisition (OH or CH)
  - Seismic profiles

Monitoring during drilling and open hole

- Continuous monitoring during the whole reservoir life
- It can be at well scale or field scale
- Through drilling, coring, logging, production and seismic
- Main data gathering methods during drilling: MWD, LWD, coring and open hole logging
- The most important parameters are saturation and pressure

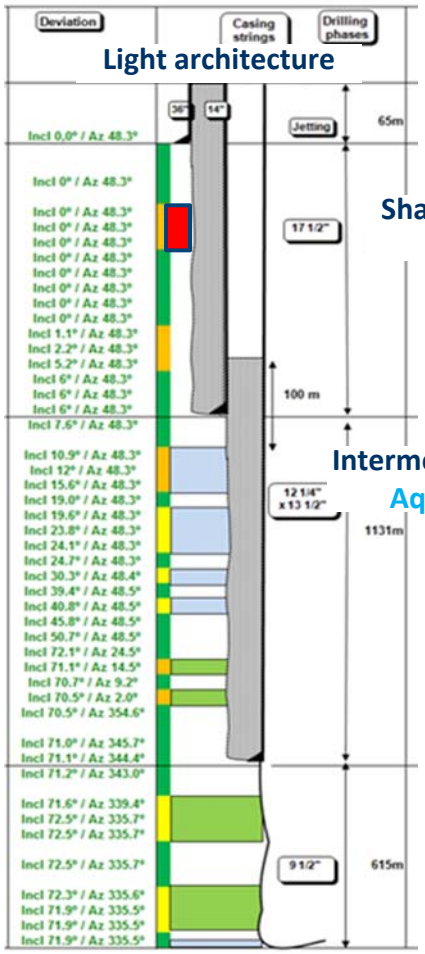
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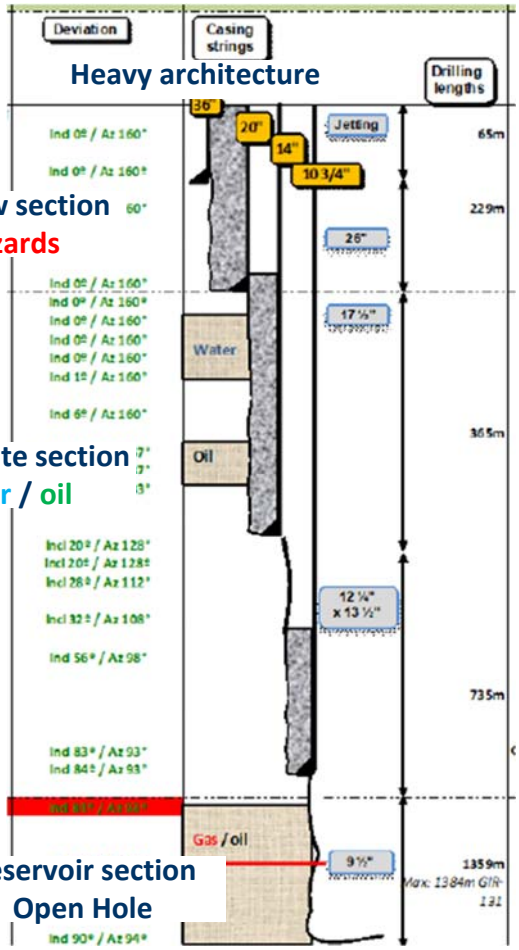
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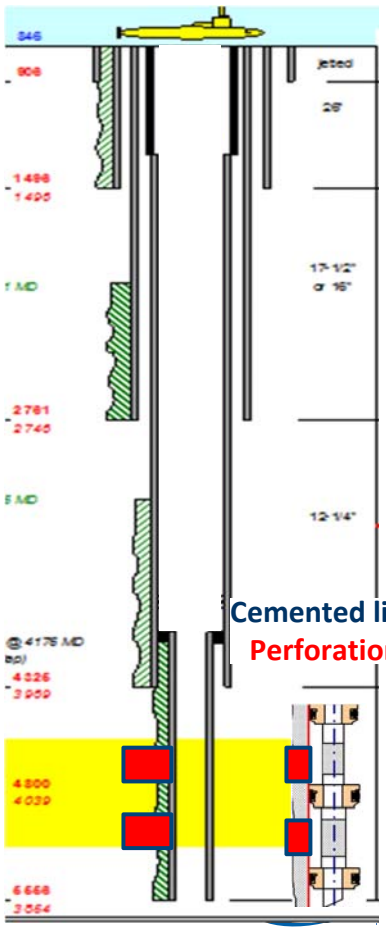
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Cement evaluation / examples of well architectures

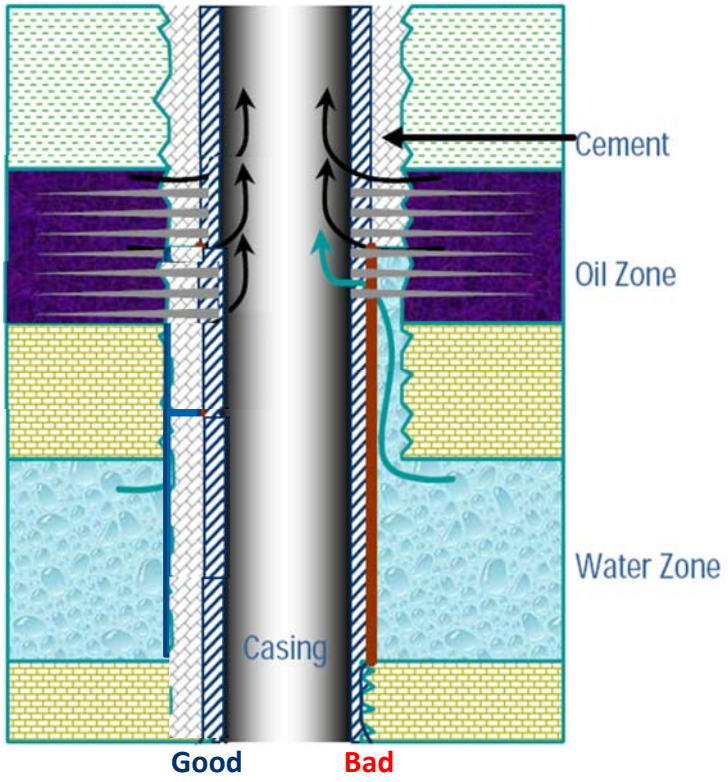






Cement evaluation

Goals



WHEN?

Generally during well drilling

To evaluate a cement job

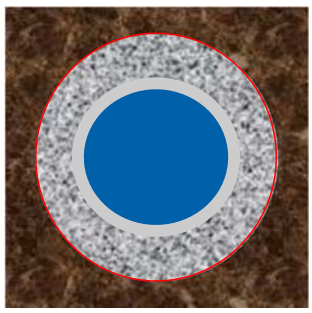
- To check the integrity of cement
- To verify zonal isolation
- To determine the cement strength
  - Is there any channel?
  - Is it necessary to repair?
  - Will it be possible to repair?

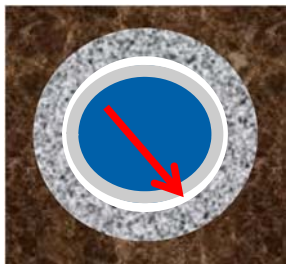
    (SQUEEZE job)
  - Where is the top of the cement?

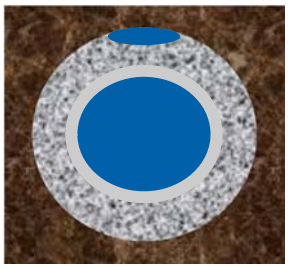
Inefficient isolation induces issues:

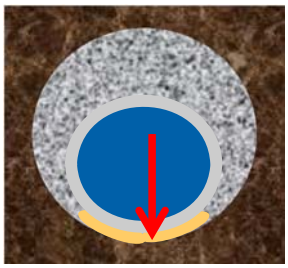
- Mixing of unwanted fluids
- Invading fluids [crossflow]
- Fluids escaping to surface
- Casing collapse
- Casing corrosion

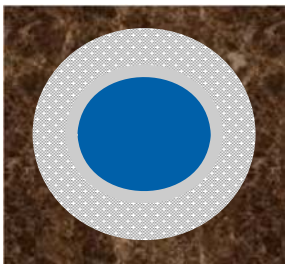
Imperfections in the cement sheath

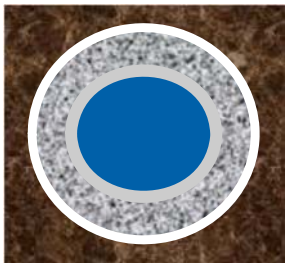


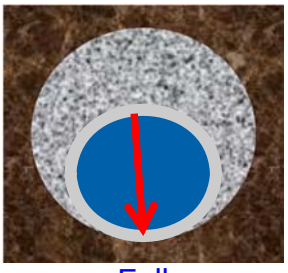

Microannulus casing/cement

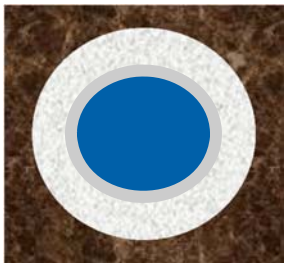

Water channel

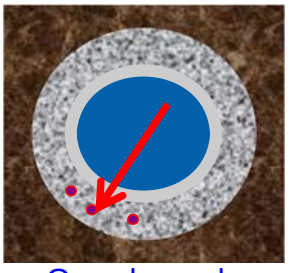

Mud channel
Gelled mud narrow side


Gas invasion


Microannulus cement/formation

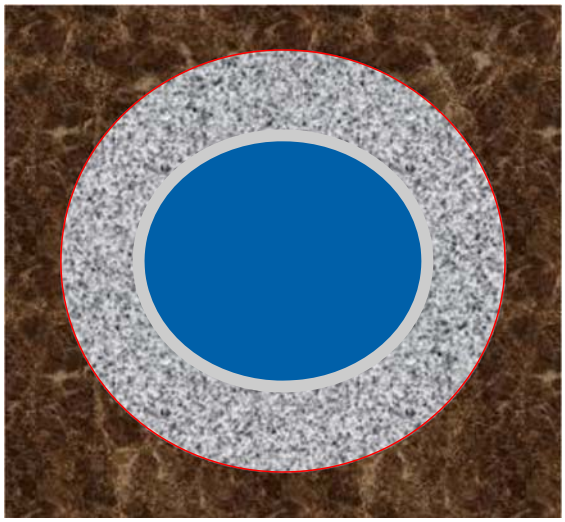

Full eccentration
casing in contact with formation


Weak cement


Gas channels

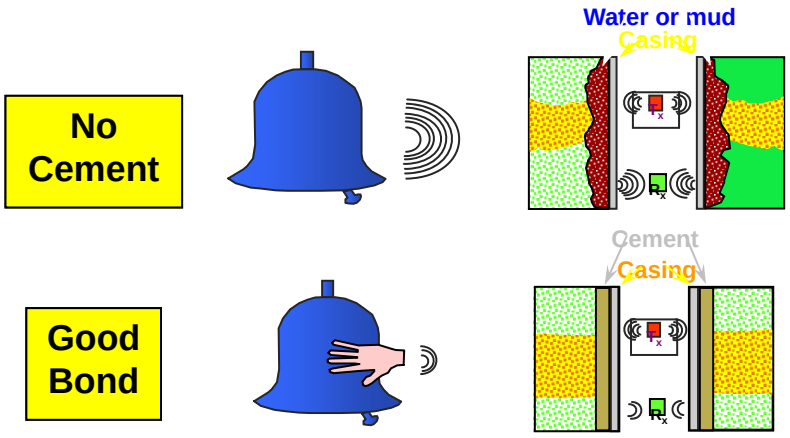
Types of tools

- **Temperature → TOC**
- **Sonic tool**
  - CBL-VDL
  - SCMT
  - SBT (Baker)
- **Ultra-Sonic tool**
  - USIT
  - CAST V (Halliburton)



Cement acoustic evaluation: fundamentals

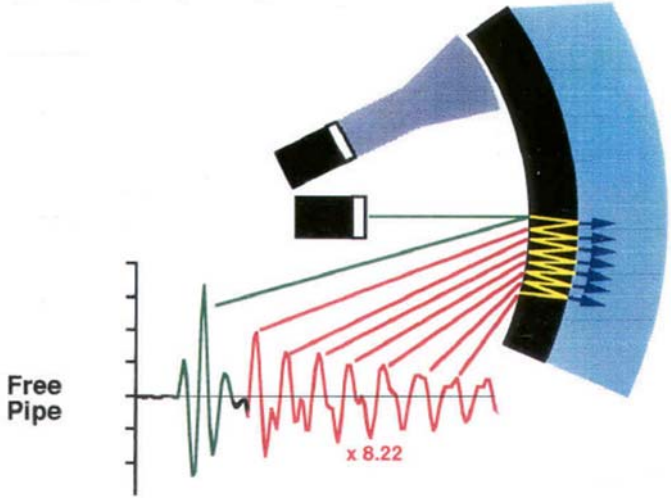
- **The resonance principle**
- **When the casing is bonded to hard cement, the vibrations in the casing are attenuated proportionally to the bonded surface area.**

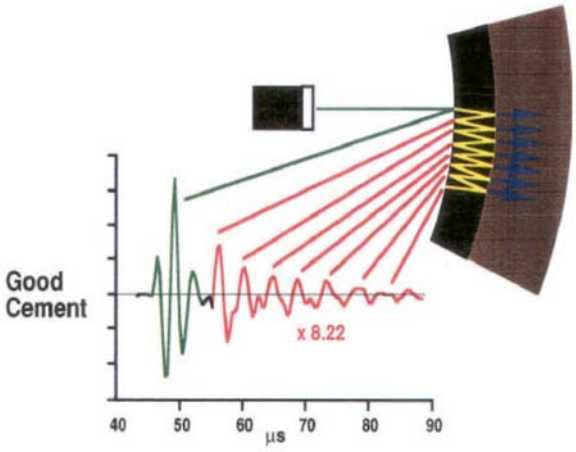


- **CBL/VDL records and measures the transmitted vibrations.**
- **USIT from the reflected vibrations provides a quality value of the cement behind the casing.**

Ultra Sonic Imager principle

- Ultrasonic tool operating between 200 to 700 kHz
- Full casing coverage 3 cm (rotating transducer)
- Cement evaluation & casing corrosion and wear

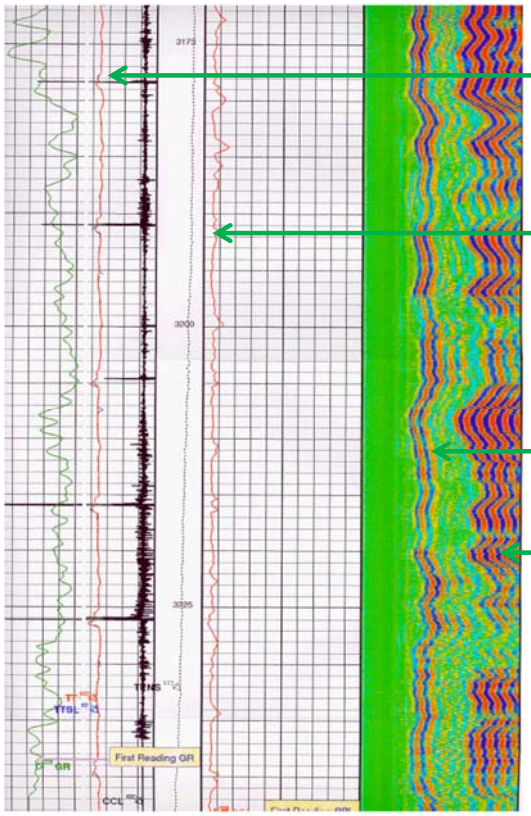




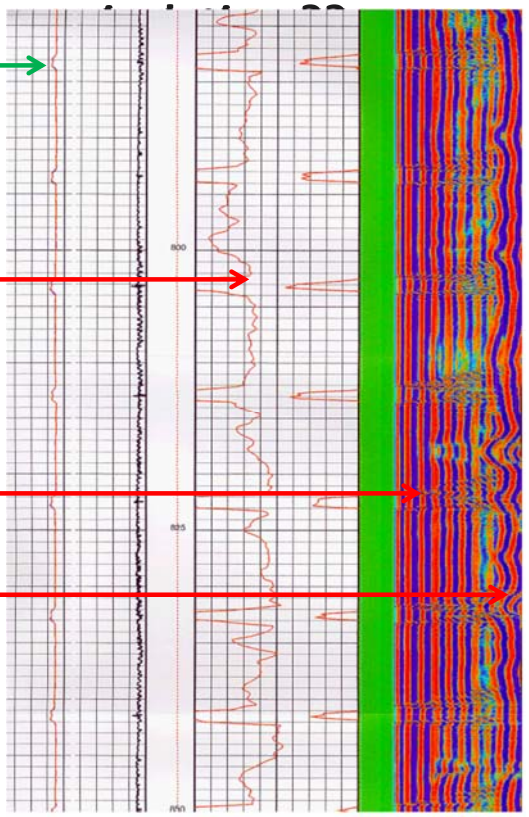
Free Pipe **Good cement**

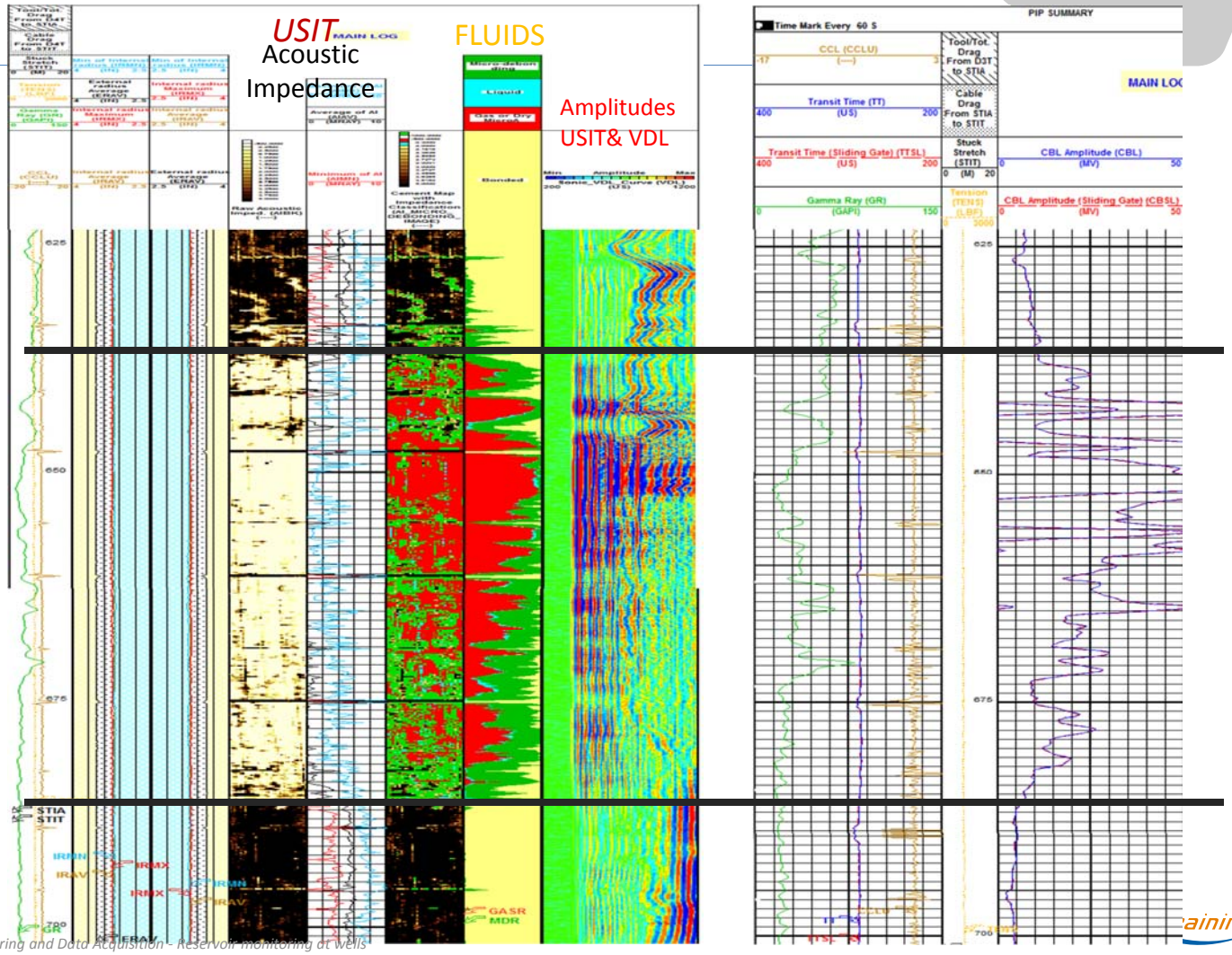
Cement acoustic evaluation

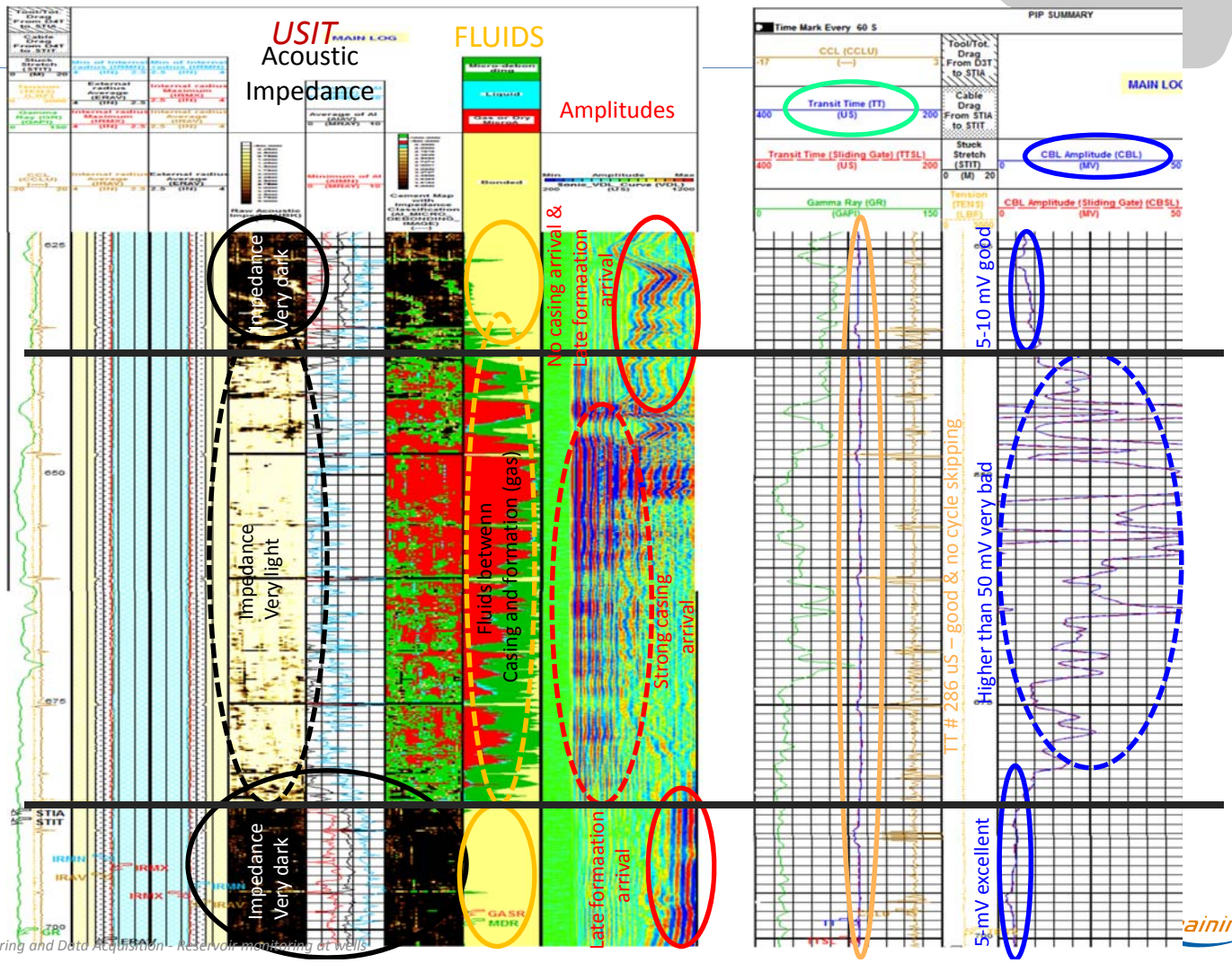
good CBL **poor CBL**



- **Check quality**
  - **Look at TT curve**
    (no skipping ?)
- **Check CBL curve**
  - **low amplitude** (<5mV)
    high amplitude
- **Verify VDL**
  - **No casing arrivals**
    casing arrivals
  - **Formation arrivals**
    Fm weak arrivals




USIT MAIN LOG
Acoustic
Impedance
FLUIDS
Amplitudes
USIT& VDL
PIP SUMMARY
Time Mark Every 60 S
CCL (CCLU)
Transit Time (TT)
Transit Time (Sliding Gate) (TTSL)
Gamma Ray (GR)
Tool/Tot. Drag From D3T to STIA
Cable Drag From STIA to STIT
Stuck Stretch (STIT)
Tension (TENS)
CBL Amplitude (CBL)
CBL Amplitude (Sliding Gate) (CBSL)
MAIN LOG
STIA
STIT
GR
GASR
MDR


USIT MAIN LOG
Acoustic
Impedance
FLUIDS
Amplitudes
PIP SUMMARY
Time Mark Every 60 S
Impedance Very dark
Impedance Very light
Impedance Very dark
Fluids betwenn Casing and formation (gas)
No casing arrival & Late formation arrival
Strong casing arrival
Late formation arrival
TT # 286 uS – good & no cycle skipping
5-10 mV good
Higher than 50 mV very bad
5 mV excellent
MAIN LOG
STIA
STIT
GR
GASR
MDR

Cement bond interpretation: solutions

- **What can you say about the transit time, knowing that the true TT is 286 micro-sec. Any cycle skipping?**
  - Quality check is Okay, no cycle skipping
- **Using in turn the CBL, VDL, and USIT determine the cement bond quality for the following zones:**

Zone	Bond quality	CBL	VDL	USIT
Above 638 m	good	5-10 mV	Late formation arrivals	Impedance very dark
638 – 687 m	Very bad	Higher than 50 mV	Strong casing arrivals	Impedance very light
Below 687 m	Very good	5 mV	Late formation arrivals	Impedance very dark

- **Explain the possible cause of bad cement job?**
  - The presence of the gas zone is a probable cause: see USIT

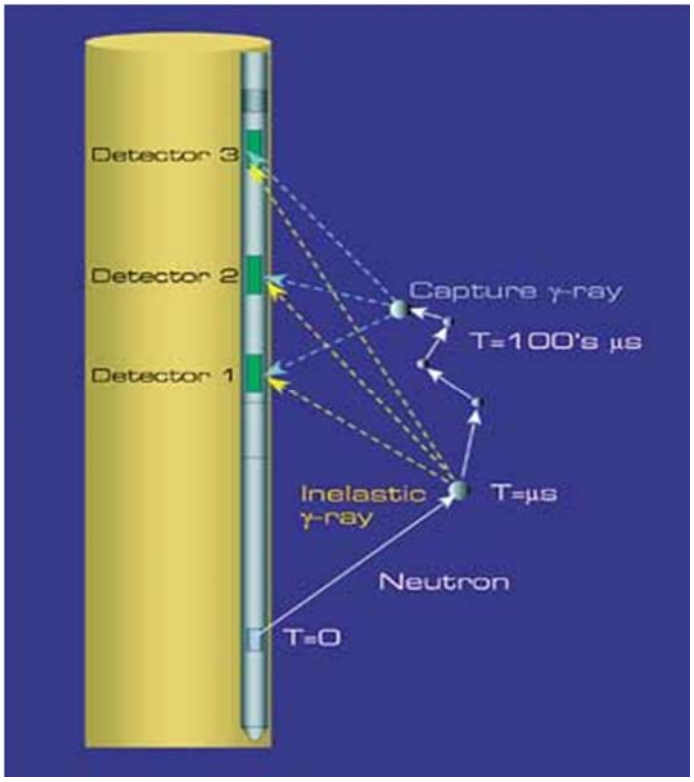
Saturation cased hole logging

- **When?**
  - During the field life, after exploitation has been implemented
  - Better to have a reference recorded just after well start-up
  - In case of EOR the reference can be just before EOR operation start-up
- **Objectives**
  - Saturation monitoring
  - Fluid movements:
  - Gas cap expansion,
    - OWC evolution,
    - Gas /water injection flow paths (behind casing)
    - To diagnose production problems (ex: water entry)
    - To plan work-over and enhanced recovery

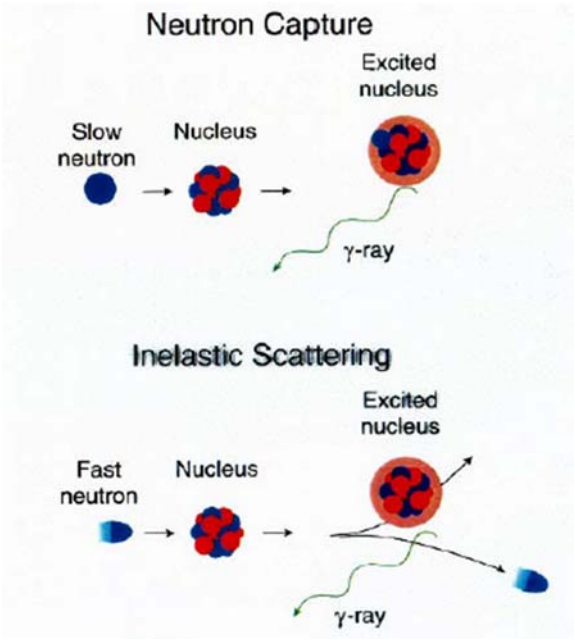
Saturation cased hole logging

- **Main cased hole saturation logs (formation evaluation)**
  - Pulsed neutron techniques (C/O mode) (Res Sat Tool)
    - RST (Schlumberger) RPM (Baker) TMD-L (Halliburton)PND-S (Computalog)
  - Pulsed neutron techniques (Sigma mode) (Thermal Decay Time)
    - TDT(Schlumberger), PDK-100, RPM (Baker), TMD-L (Halliburton), PND-S (Computalog), PNN (Hotwell)
  - Resistivity log (Cased Hole Formation Resistivity CHFR)

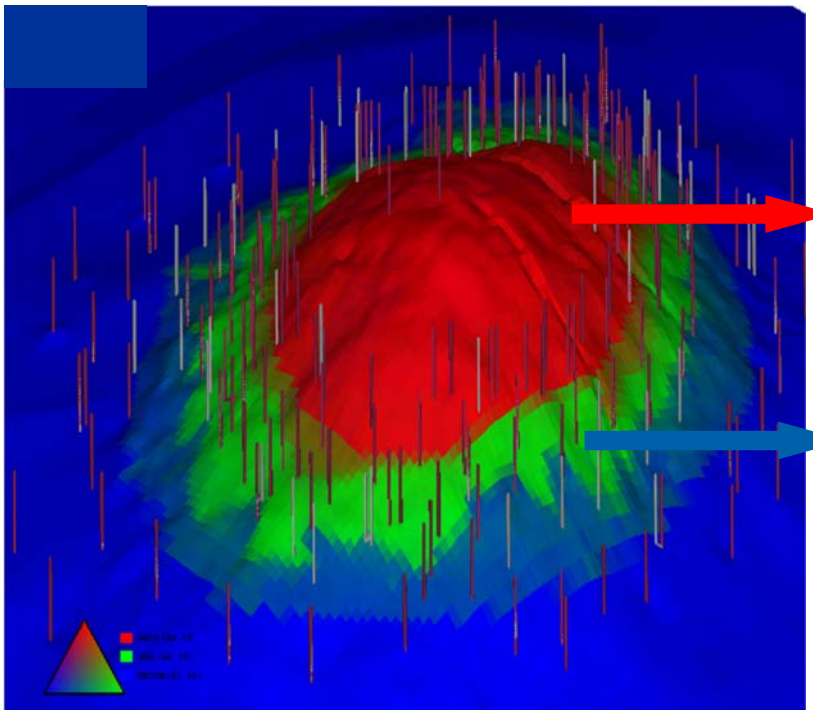
Principle of sigma (TDT) & C/O (RST) measurements



- Sigma: capture gammas
- C/O: inelastic gammas



Example 1: fluid movements monitoring



Gas cap fluid in place

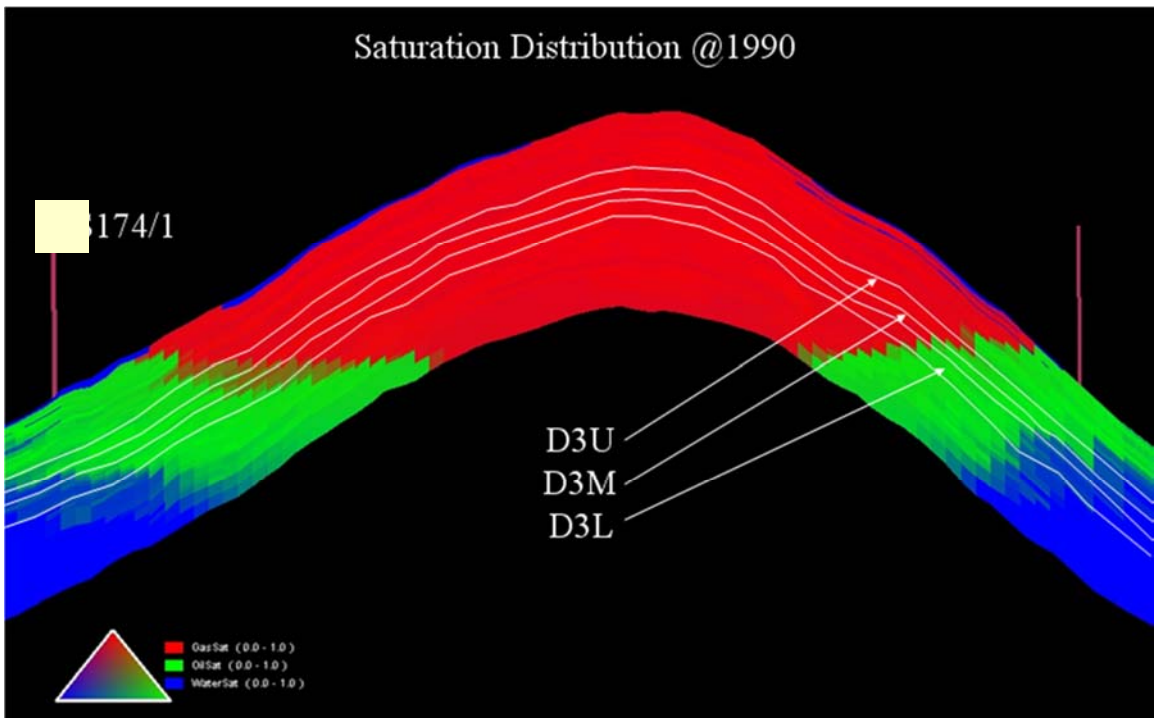
- GIP
- CIP

Oil pool fluid in place

- OOIP
- SGIIP

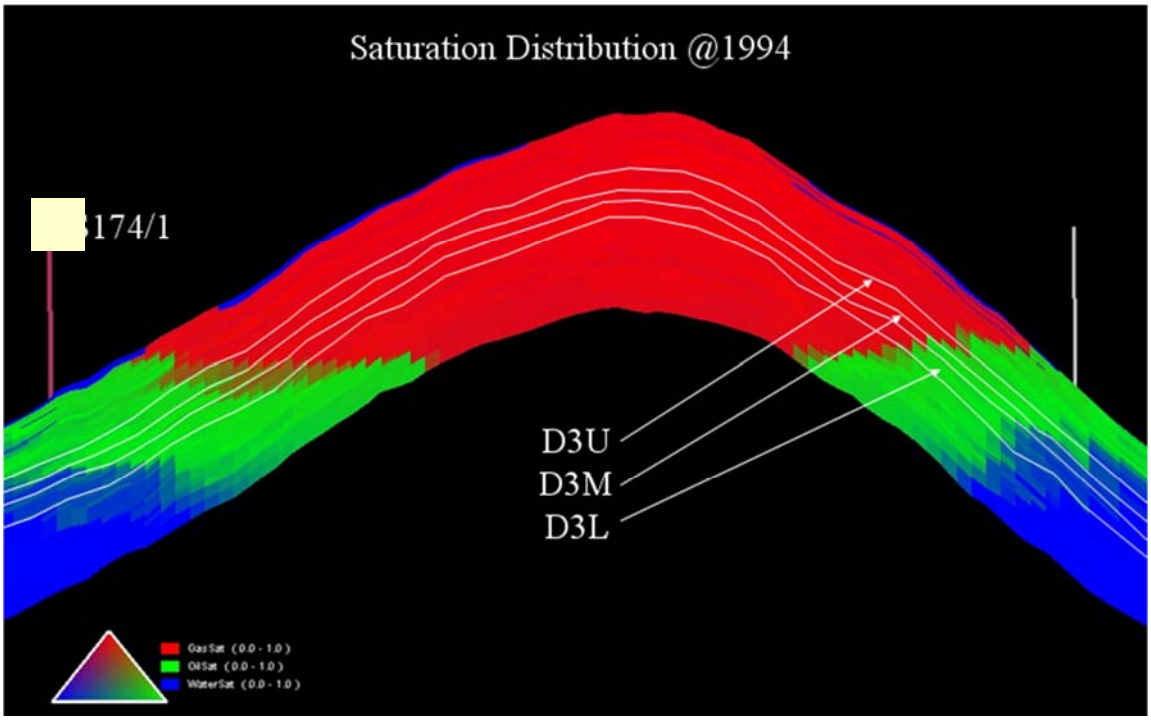
Example

Monitoring of fluid movements



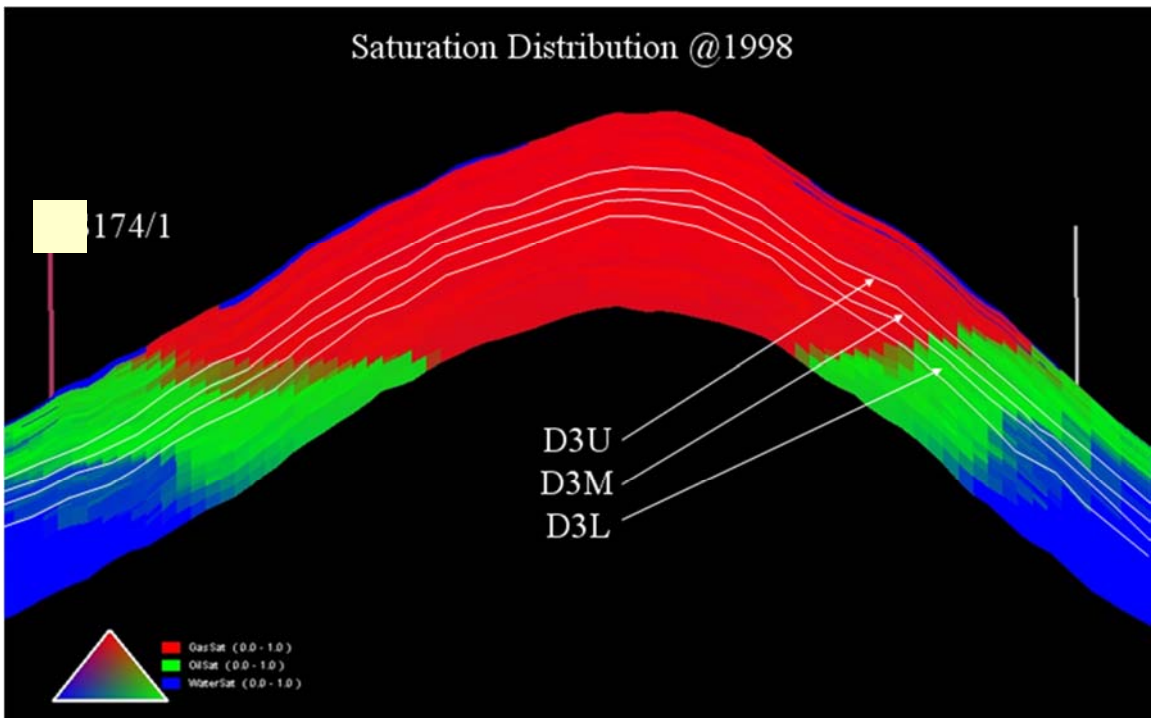
Example

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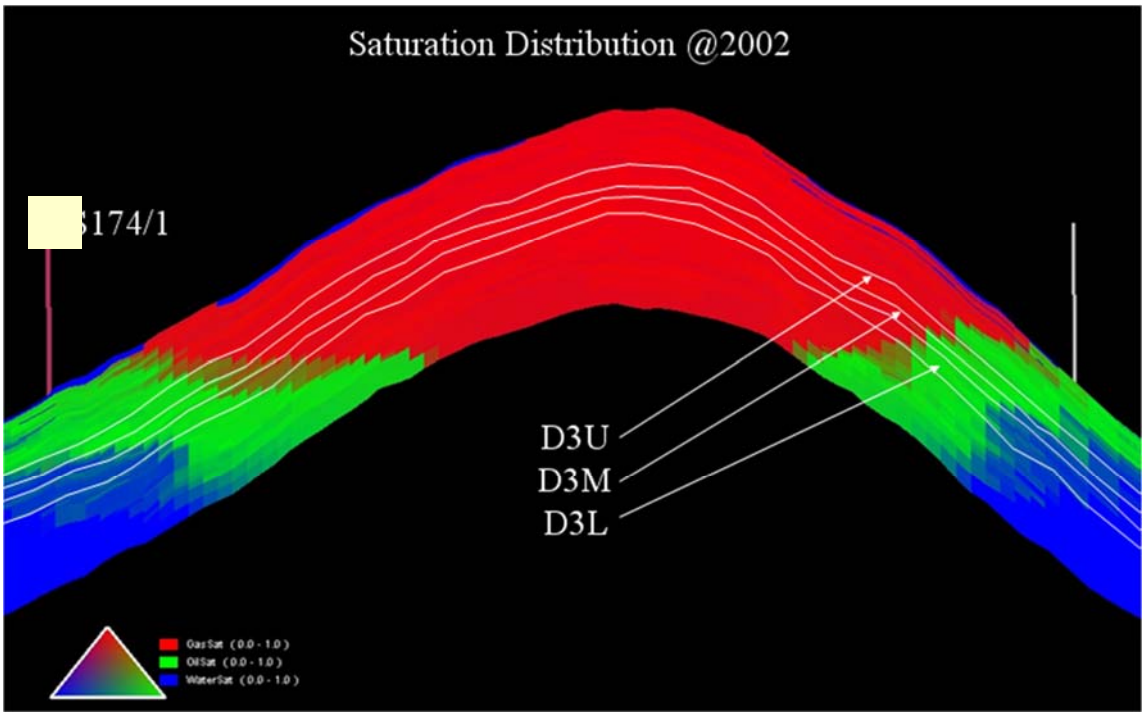
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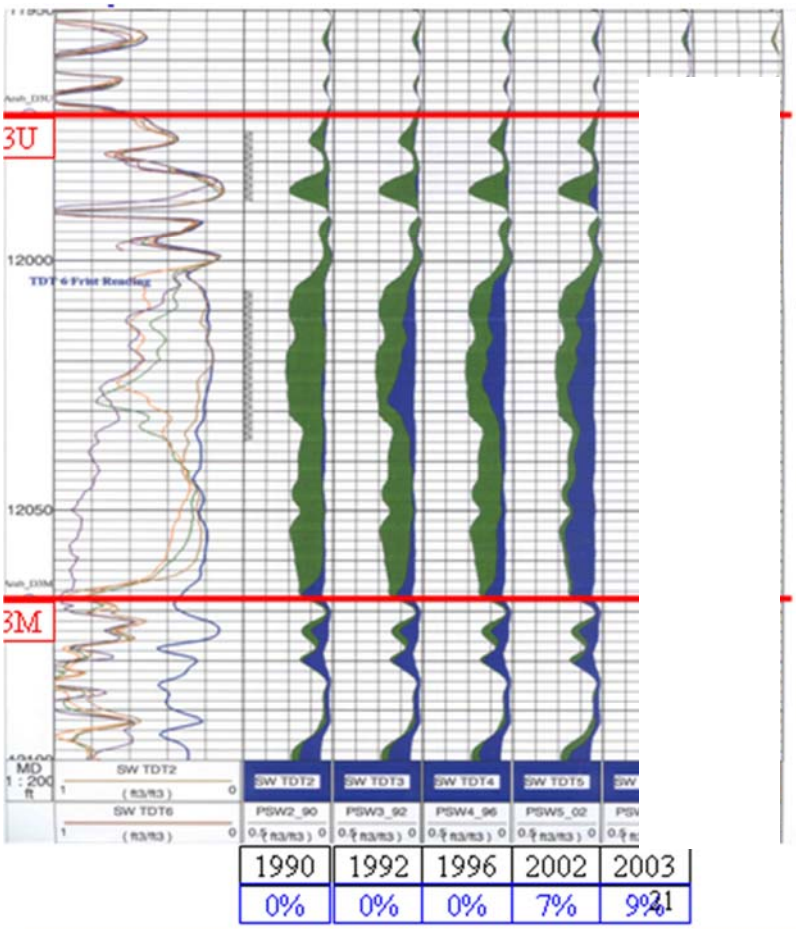


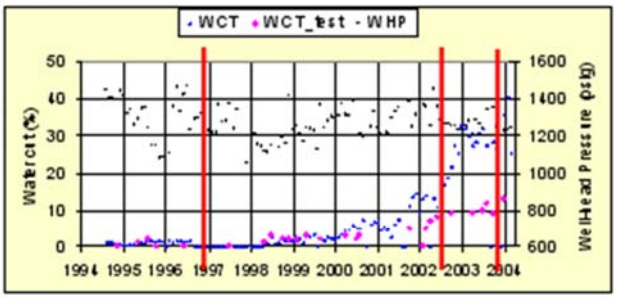
Example

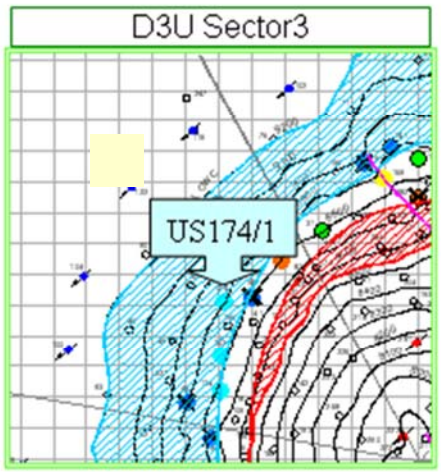
Monitoring of fluid movements



Example: monitoring of fluid movements



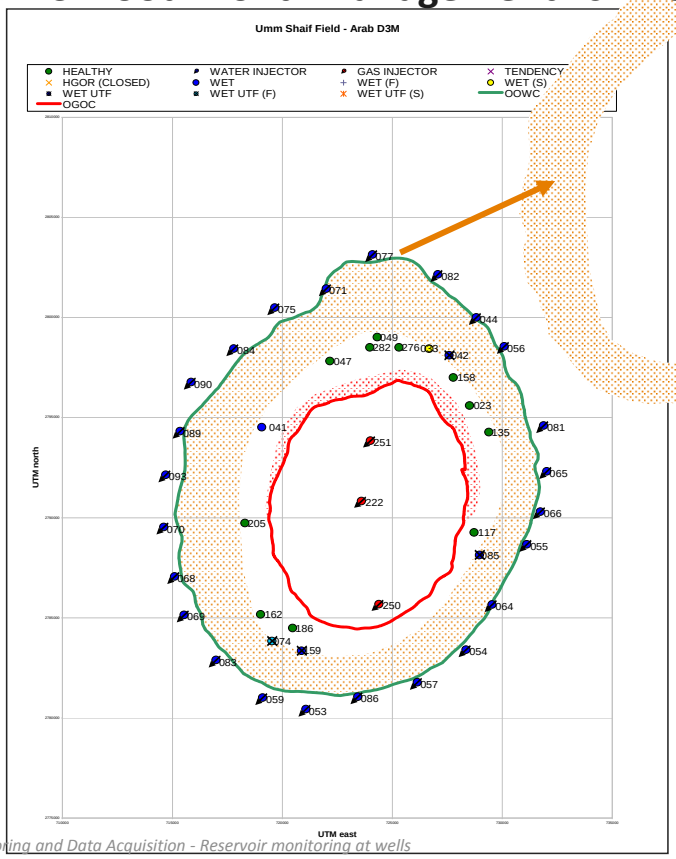


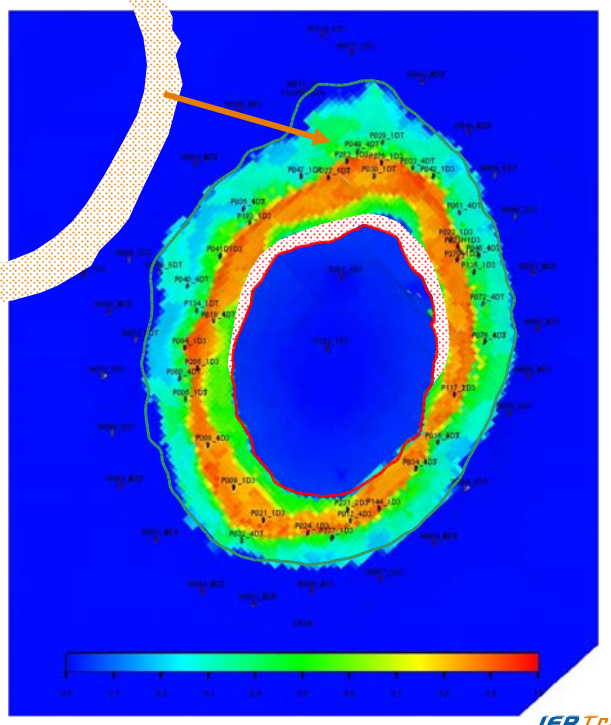


Example

Monitoring of fluid movements

- D3 Flood Front: Management vs. Model

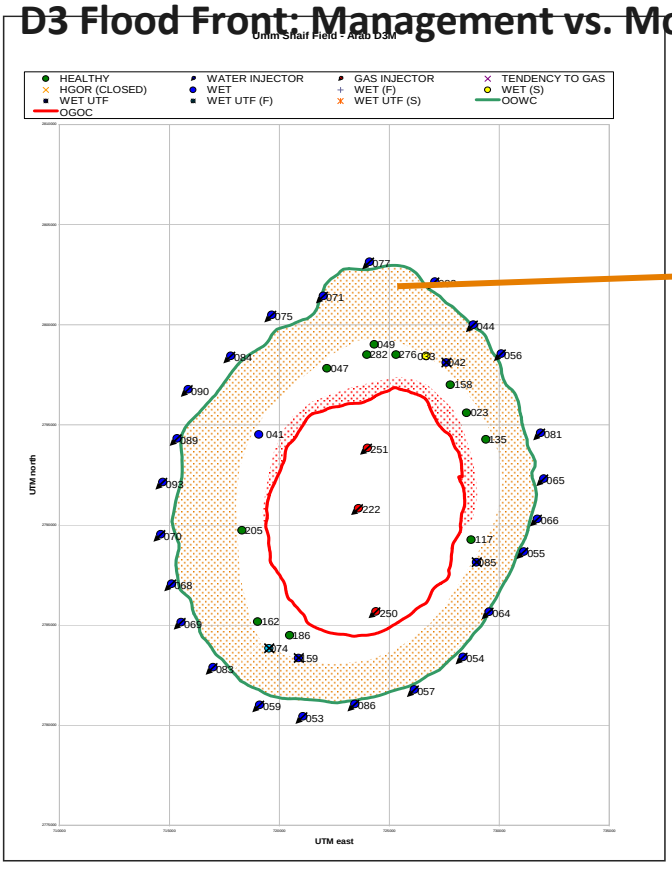


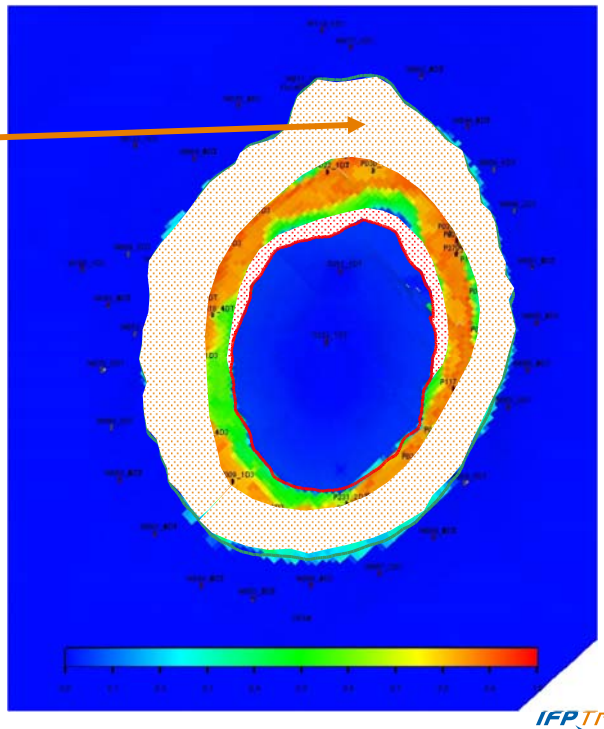


Example

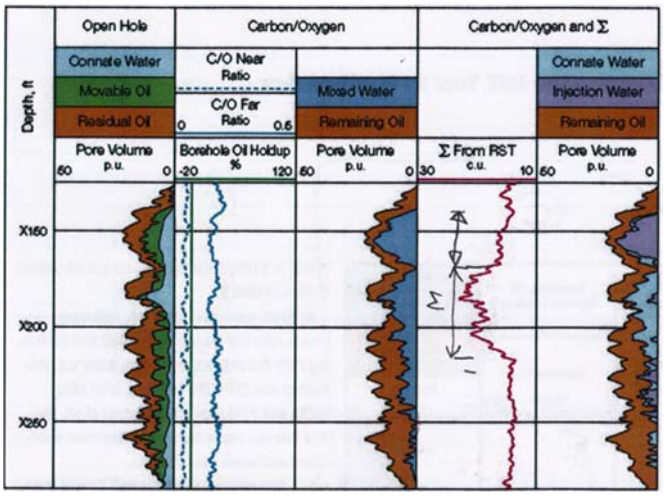
Monitoring of fluid movements

- D3 Flood Front: Management vs. Model





Interpretation examples



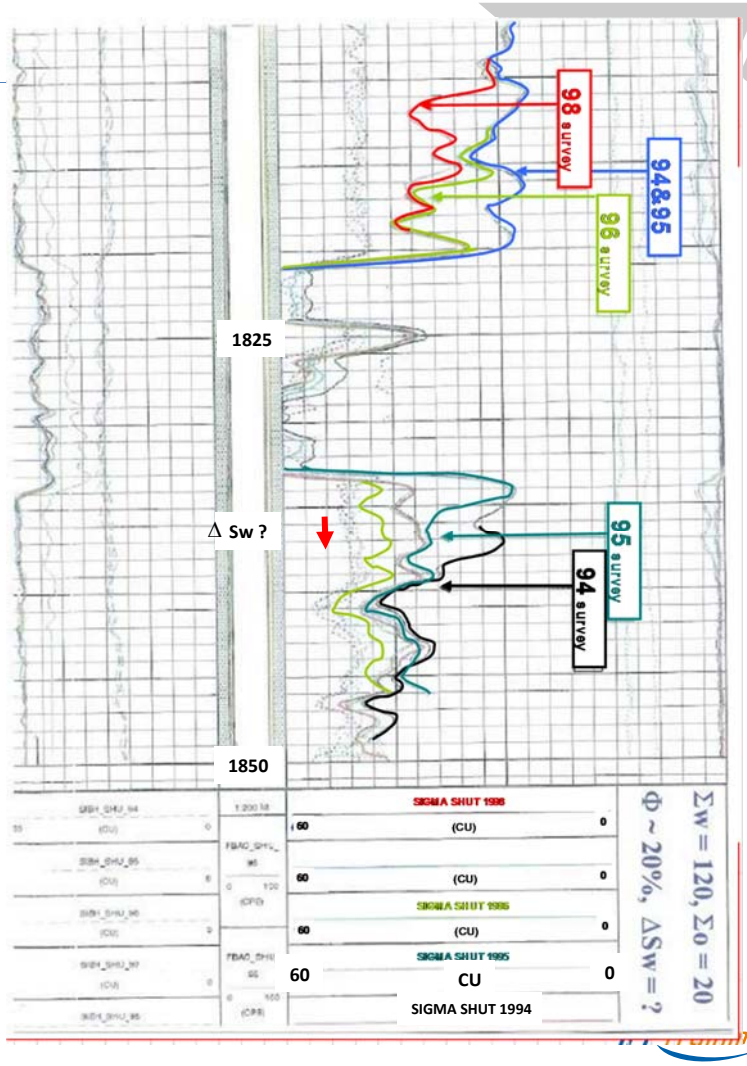
- C/O ratio is unable to see a difference between various types of waters.
- Sigma mode sees salt water in the zone 170-210 ft and C/O ratio sees water at 140 -170 ft:
- then it means that water at top depths is fresh injection water.
- So injection water breakthrough has been detected with that technique.
- Sigma mode alone would have seen top zone as oil filled!
- Recap:
  - Σ mode sees oil or fresh water
  - C/O mode sees water
  - So fresh water present

EXO TDT

- A Thermal Decay Tool has been run at various intervals: 1994, 1995, 1996, and 1998. The sigma log measurements are displayed in the attached log. We can see that the OWC is rising.
- Assuming that the formation is shale-free sandstone, we have the following equation:

$$\Sigma_{\log 1} = \Sigma_{mat}(1-\Phi) + (\Sigma_{wat} S_{w1} + \Sigma_{oil} S_{o1})\Phi$$

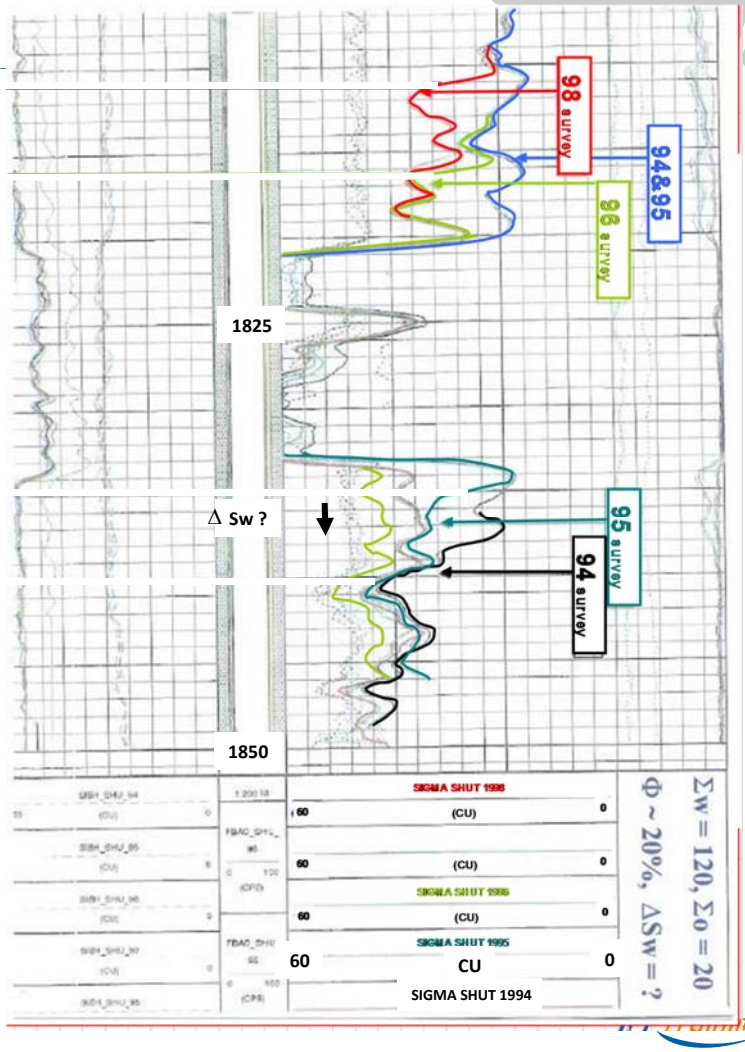
- **Question 1**: indicate on the log the position of OWC at 1994, 1995, 1996, and 1998.
- **Question 2**: by using the above equation at dates 1994 and 1995, derive by subtraction the analytical $\Delta S_w = ?$ value for
- **Question 3**: numerically apply the ΔS_w above equation and calculate for the interval marked by an arrow on the log.



Solution to question 1:

- **Question 1:** ***indicate on the log the position of OWC at 1994, 1995, 1996, and 1998.***

- **Solution:**
  - OWC_{94}= [redacted]
  - OWC_{95}= [redacted]
  - OWC_{96}= [redacted]
  - OWC_{98}= [redacted]



- **Note**

Note

Note

Note

Solution to question 2:

By using the equation at dates 1994 and 1995, derive by subtraction the analytical value for $\Delta S_w = ?$

For a formation such shale-free sandstone, we have the following equation: $\Sigma_{\log 1} = \Sigma_{mat}(1-\Phi) + (\Sigma_{wat} S_{w1} + \Sigma_{oil} S_{o1})\Phi$

$$\Sigma_{\log 1} = \Sigma_{mat}(1-\Phi) + (\Sigma_{wat} S_{w1} + \Sigma_{oil} S_{o1})\Phi$$

$$\Sigma_{\log 2} = \Sigma_{mat}(1-\Phi) + (\Sigma_{wat} S_{w2} + \Sigma_{oil} S_{o2})\Phi$$

$$\Delta S_w = S_{w2} - S_{w1}$$

$$\Delta\Sigma_{\log} = \Sigma_{\log 2} - \Sigma_{\log 1}$$

$$\Delta S_w = \frac{\Delta\Sigma_{\log}}{\Phi(\Sigma_w - \Sigma_o)}$$

Solution to question 3:

Calculate ΔS_w for the interval marked by an arrow on the log

Σ_{log1} = **22**

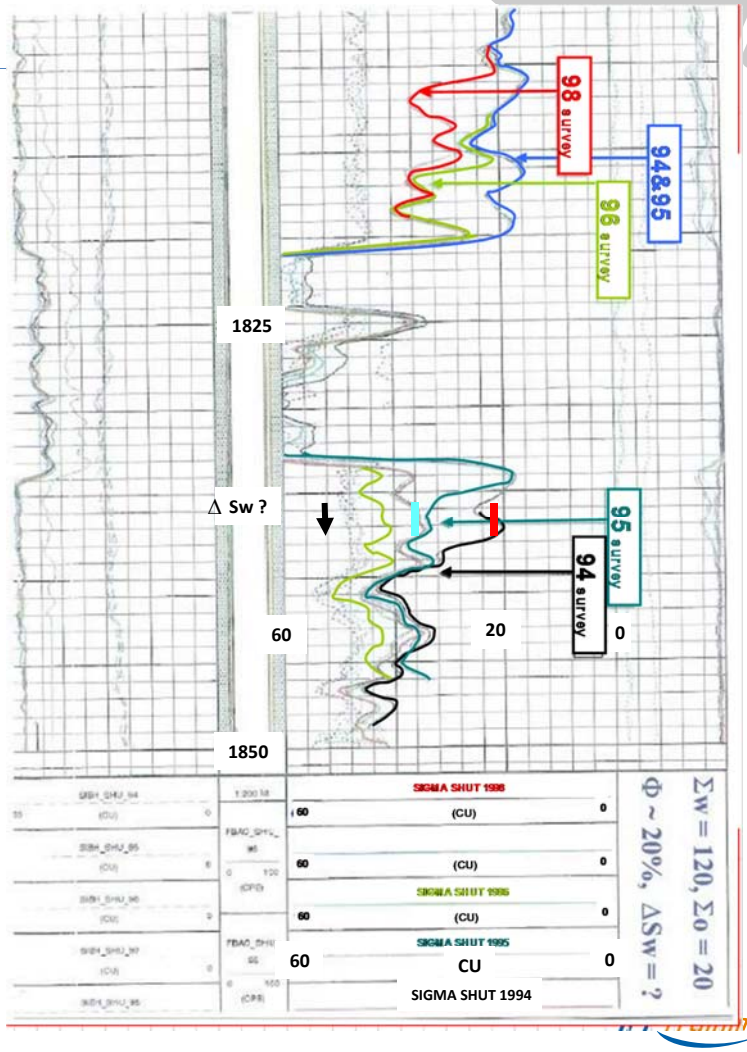
Σ_{log2} = **36**

$$\Delta\Sigma_{log} = \Sigma_{log2} - \Sigma_{log1} = 14$$

$$\Delta S_w = \frac{\Delta\Sigma_{log}}{\Phi(\Sigma_w - \Sigma_o)}$$

=14 / (.20 x (120 -20))

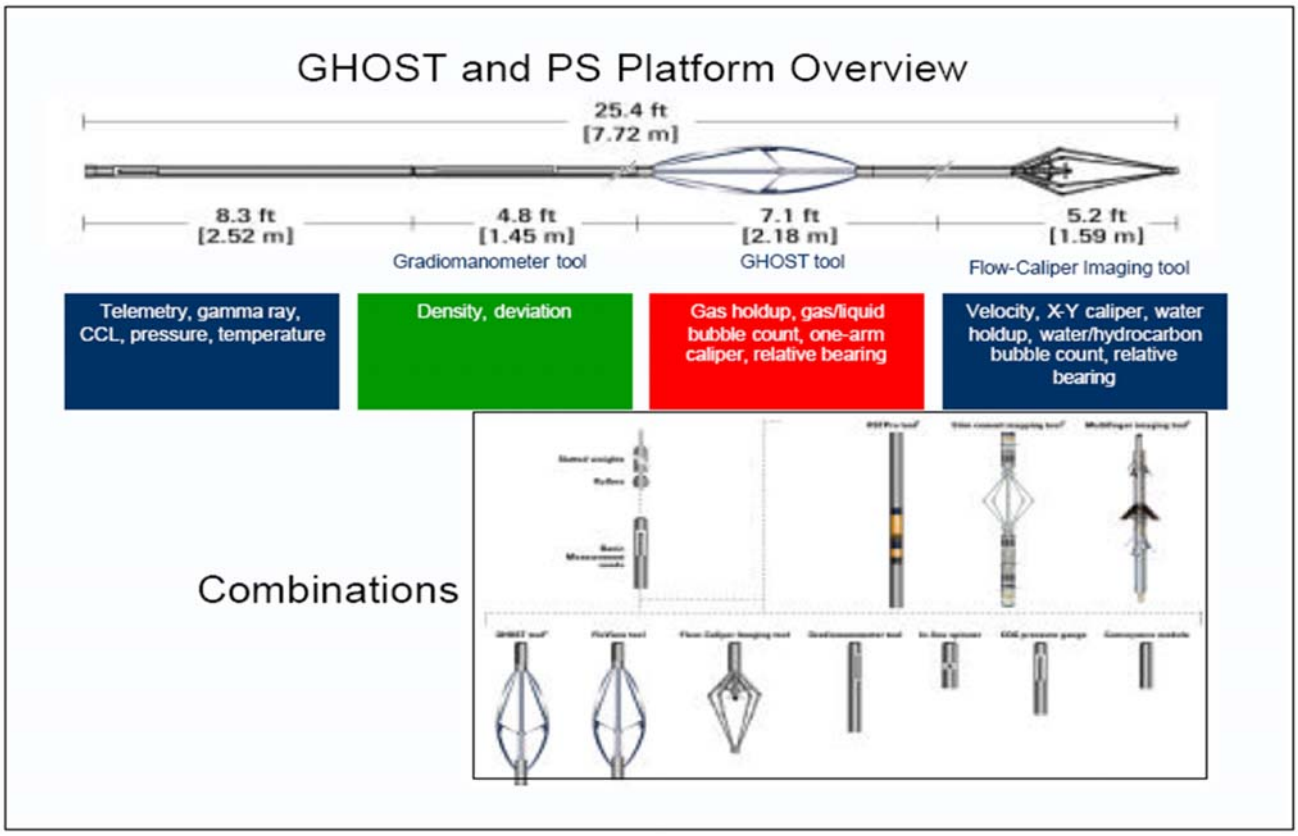
$$\Delta S_w = 0.70$$



Production / Injection logging

- **WHEN?**
  1. **At start-up to confirm potential vs expectation**
  2. **More - During field life to confirm the analysis and validate the interventions**
- **Goals**
  - To determine the reservoir characteristics
  - To identify fluid movements
  - To evaluate the efficiency of the completion
  - To evaluate the production / injection profiles at well
  - To evaluate the efficiency of the treatment
  - To detect thief zones
- **To provide elements / data**
  - For feeding / populating models – History matching
  - For proposal for intervention on wells: stimulation/acid, Zone shut-off / isolation (Water, gas, ..)

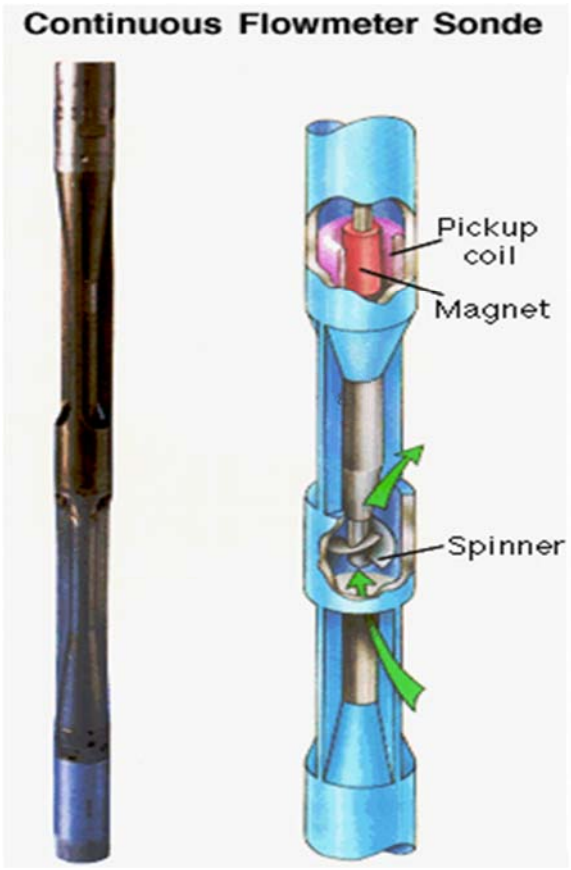
Example - Production logging tools



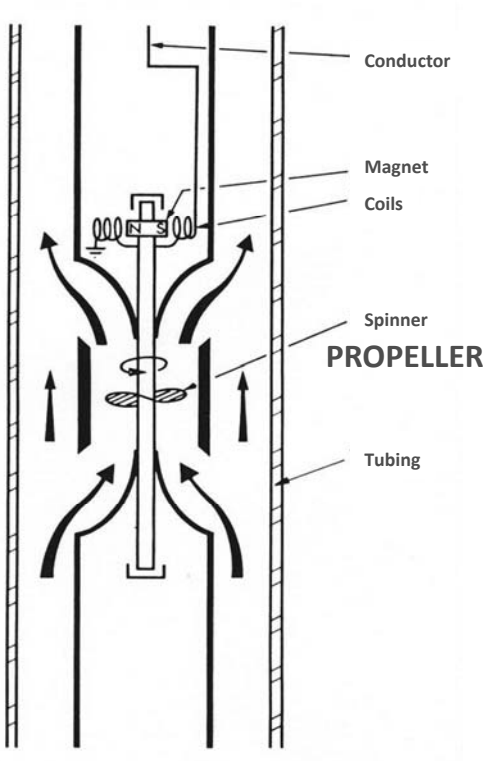
Schlumberger Document

Production logging tool (PLT)





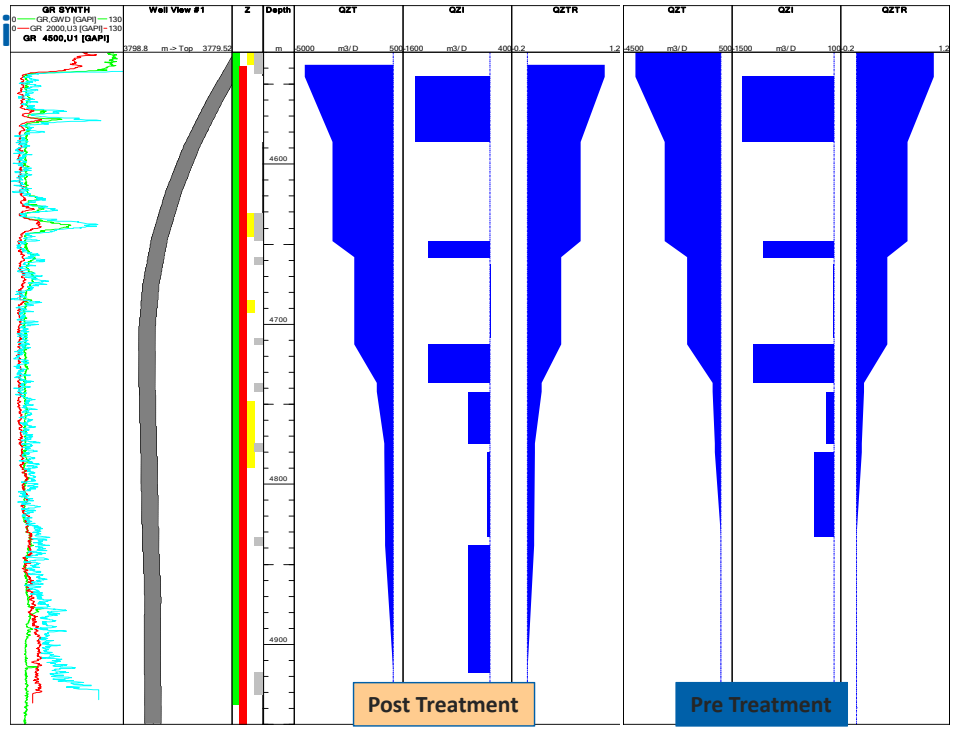
From Schlumberger

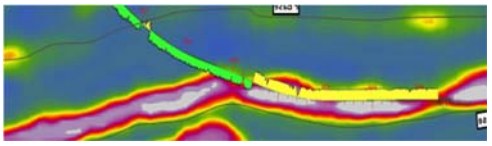


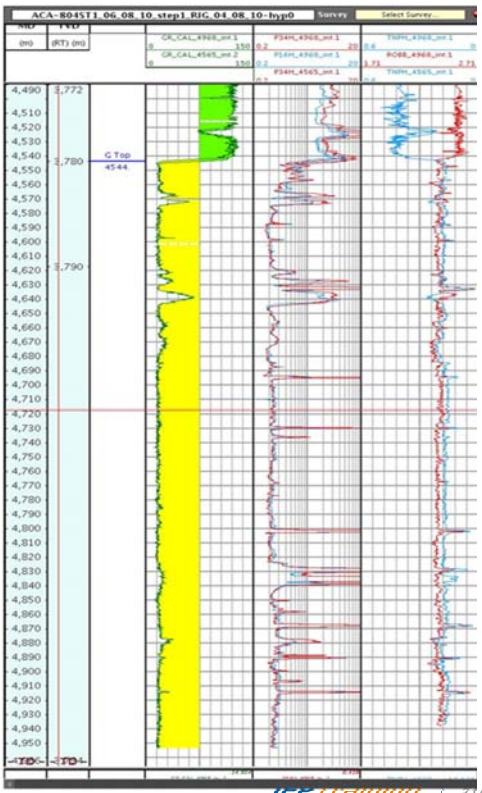
Typical production logging tools & recommendations

- **Flowmeter:**
  - Try to get zero flow zone near TD to get in-situ spinner calibration
  - Minimum of 3 passes up and 3 passes down at different cable speeds.
- **Temperature survey:**
  - Record representative geothermal gradients at start of PLT
  - Record a full temperature profile from bottom to top of the well.
- **Gradio-manometer:**
  - Use quartz gauge to determine fluid density, & then apply necessary correction to gradio.
- **Caliper:**
  - Run a base caliper log to check for integrity of casing ID.
- **Deviated & horizontal wells:**
  - Use Flow scan imager to determine holdup and flow profiles.

Example - horizontal WI: PLT interpretation – Pre & ost aci



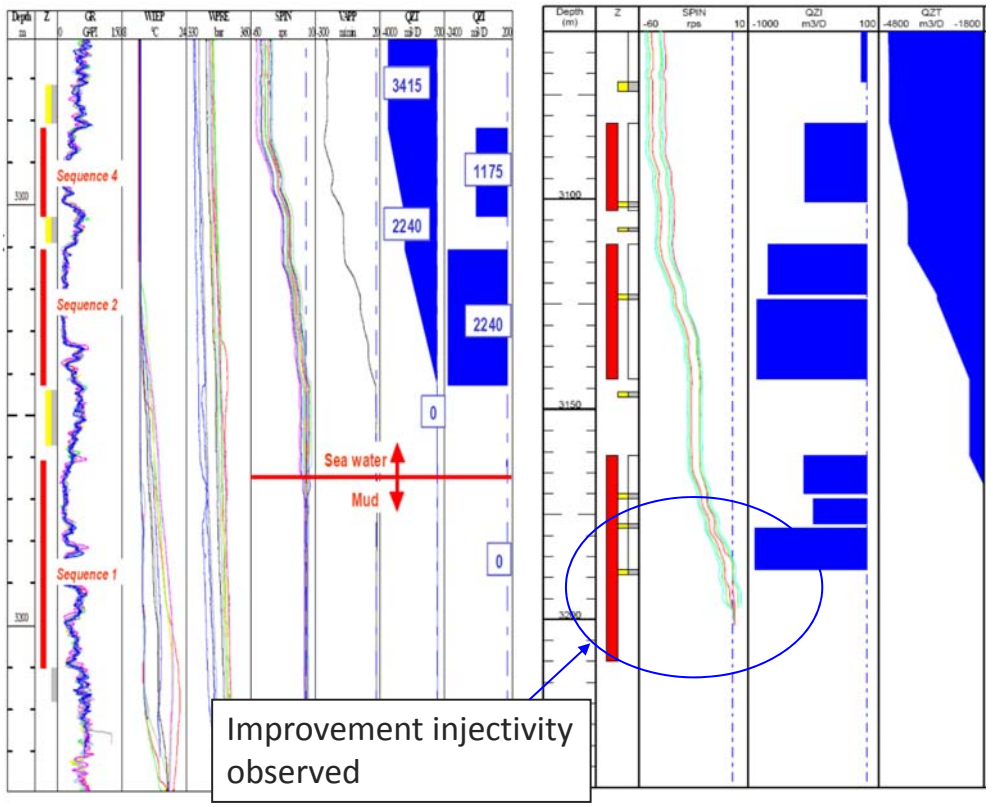




- **Interpretation shows only very minor difference in inflow profile following coiled tubing operations**
  - Slight improvement noted at in the final 25% of drain
  - Injection profile far more heterogeneous than would have been expected from log interpretation
- **Transient II : Pre coil tubing: ~100 sm³/d/bar Post coil tubing: ~110 sm³/d/bar**

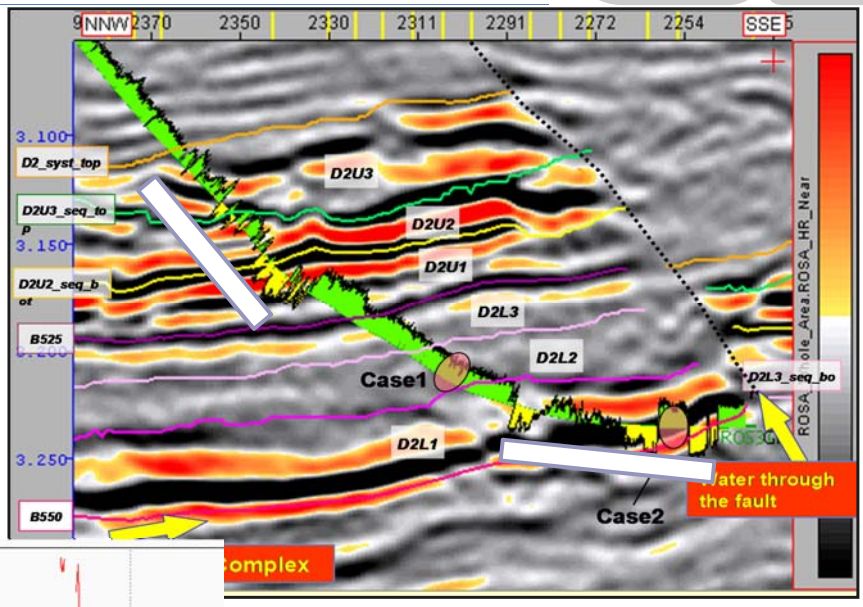
PLT example - Water Injector 9 month- delay

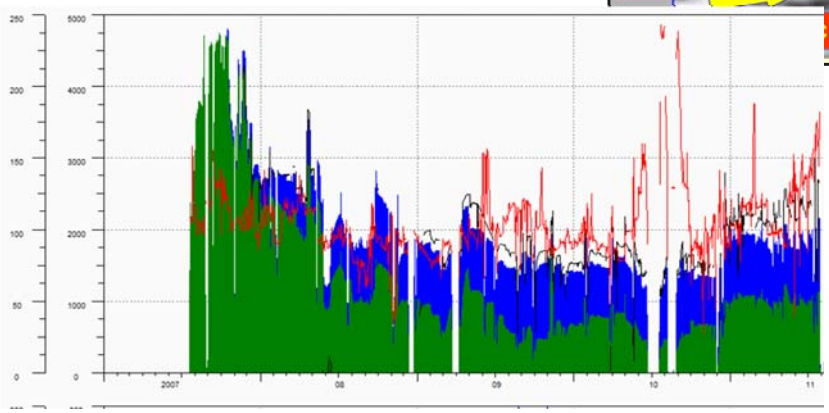
- **Injection profile shows additional injection in lowermost reservoir but**
  - differential depletion noticed during
  - Cross flow = 225 m3/d



PLT example – OP

- **Well concern of high water cut**
- **Possible water shutoff (WSO) of lower zone?**

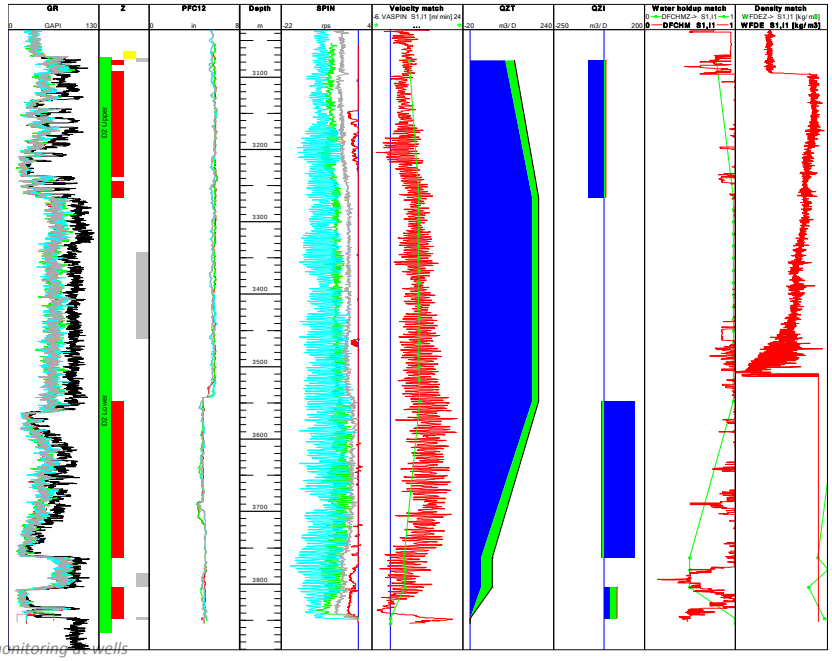




PLT example

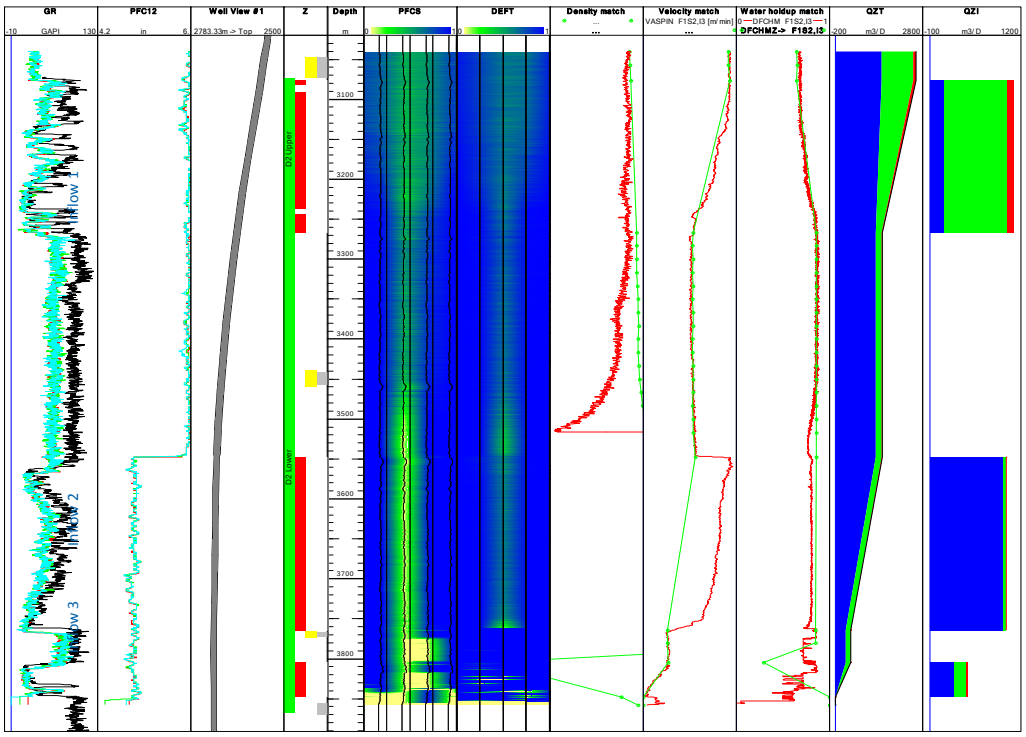
PLT interpretation: July 2011 - Shut-In summary

- **Small cross-flow observed from lower to upper zones Qliq ~250 sm3/d**
  - Quantification of cross-flow is difficult as rate is very close to the minimum detection threshold of spinner
  - Cross-flow significantly lower than 2008 PLT that reported Qliq ~1000 sm3/d



Well -PLT interpretation PLT#1

Max flow summary

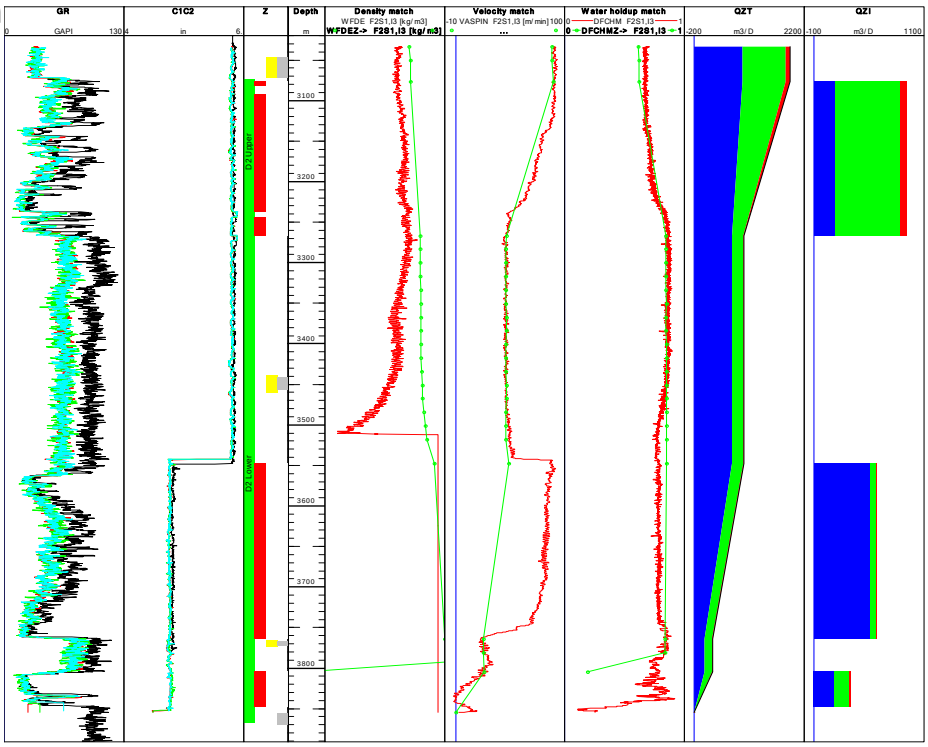


- **Lower zone contributing approximately to 60% of the total liquid with >80% BS&W**
- **Uncertainty on upper zone BS&W 0-25%**
  - Different interpretations are possible depending on whether match is weighted more heavily to water hold-up or gradio-density
  - Both measurements are very sensitive to hole inclination

Well - PLT interpretation

PLT#1 Reduced flow summary

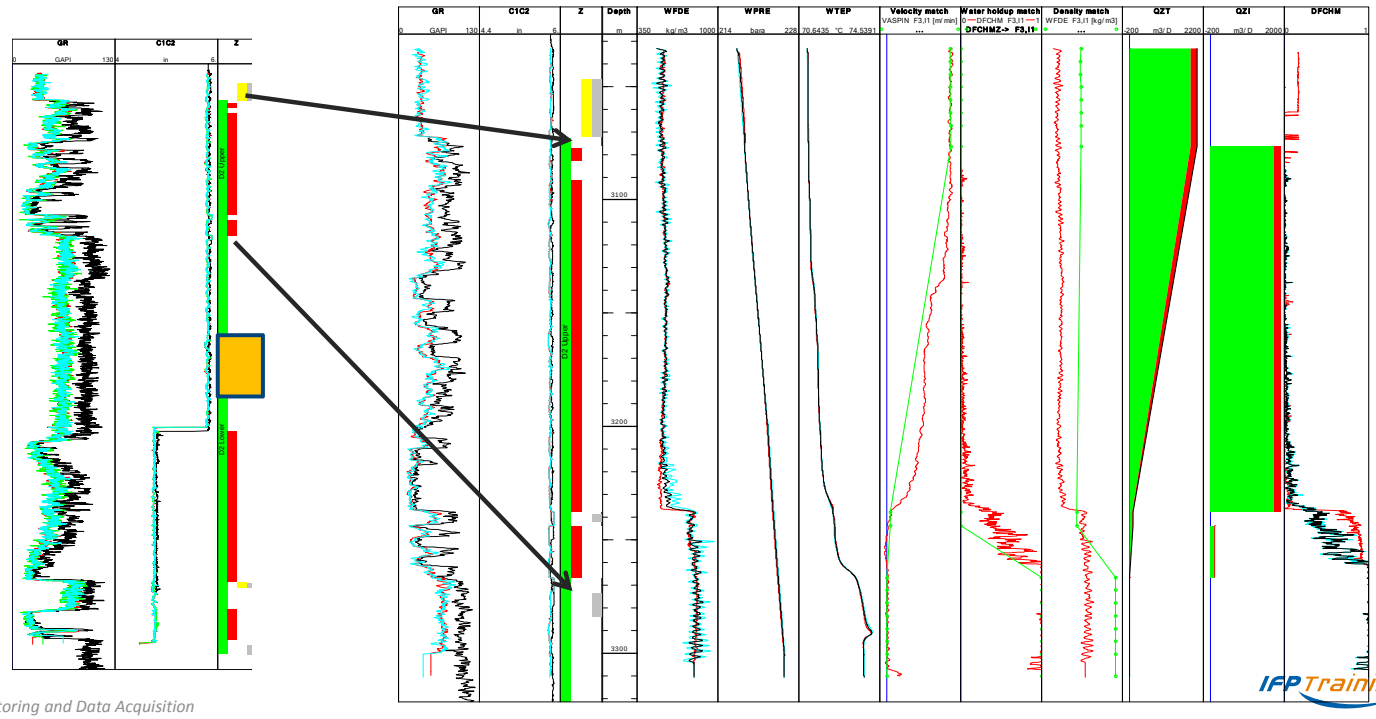
- **Interpretation at 2nd rate is very similar to the first rate**
  - The uncertainty on the upper zone BS&W remains as per the maximum rate interpretation



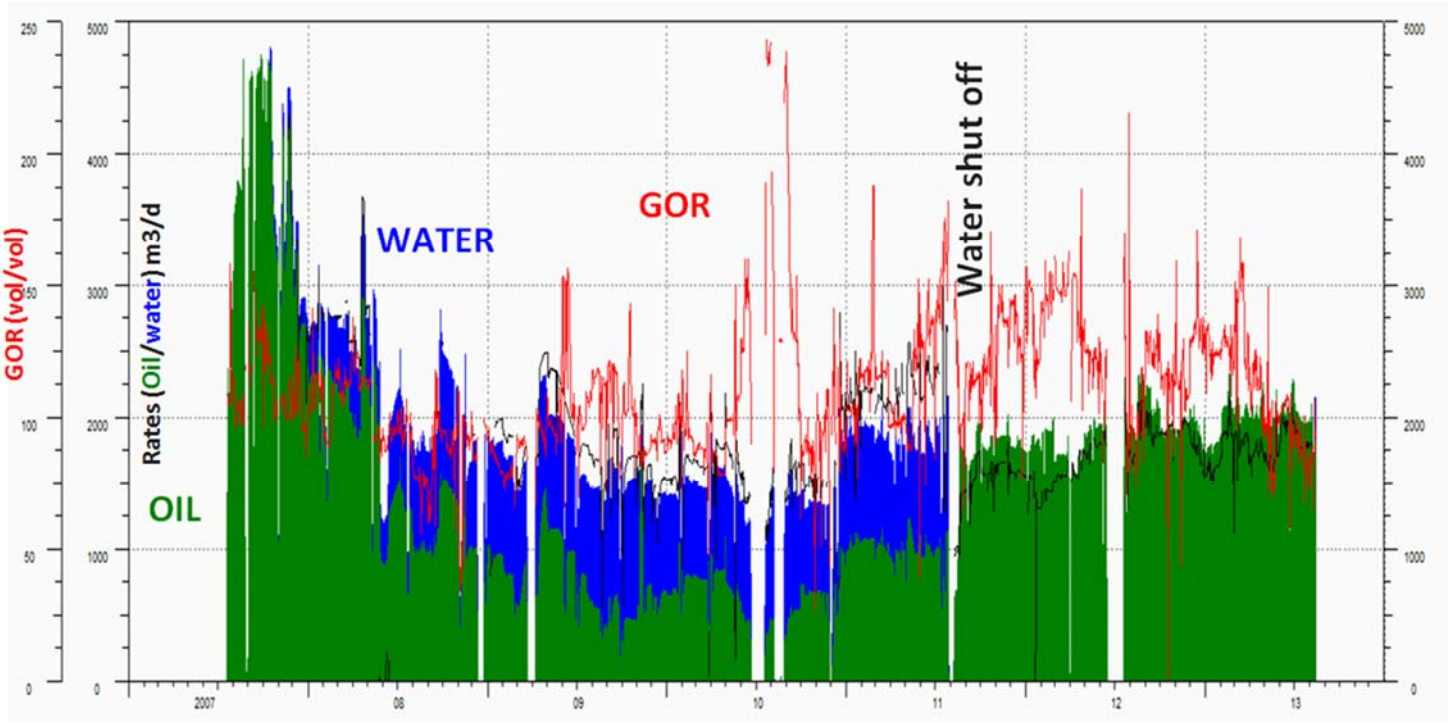
Well – WSO with

PLUG installed to isolate the lower zone: PLT#2 summary

- **PLT recorded during well test post plug setting**
  - Separator measurements Q_{oil} ~1500 sm3/d and trace BS&W → Transient well PI ~100 $sm^3/d/bar$ (Previous steady-state PI ~140 $sm^3/d/bar$)
- **Separator trace BS&W supported by PLT water hold-up sensors**
  - Evidence of small amount of water 3240 mMD probably residual from before setting the plug



Well – Production history



Monitoring in cased hole and production logging

- Main data gathering in cased hole logging: well integrity, saturation, production logging.
- The most important parameters are cementation quality, saturation and productive zone.
- Remediation: new perforations, squeezing, water shut off, new well drilling, other workover…



Data acquisition and monitoring

5. Testing / Field operation measurements

Reservoir monitoring

Testing / Field operation measurements

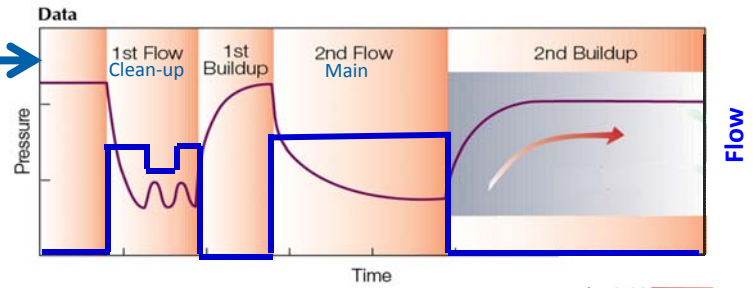
WHEN?

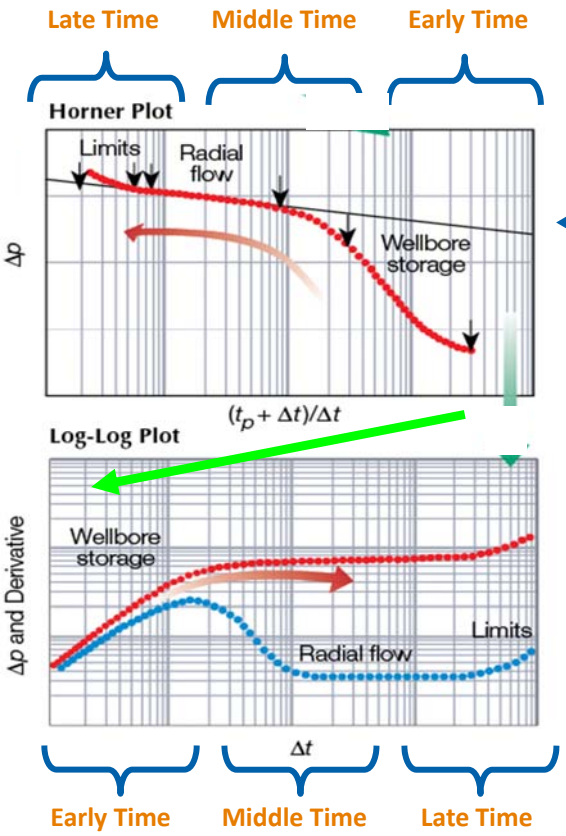
1. **At start-up to confirm potential vs expectation**
2. **During the field life to provide data on the evolution of the reservoir characteristics**

- **Tests**
  - Pressure build up, multi-rate tests, interferences…
- **Production parameters**
  - Rates, GOR, BSW, THP, THT, (BHP?), fluids (Hc/Water, chemical analysis...)

Test interpretation methodology / reminders

Typical initial well test sequence



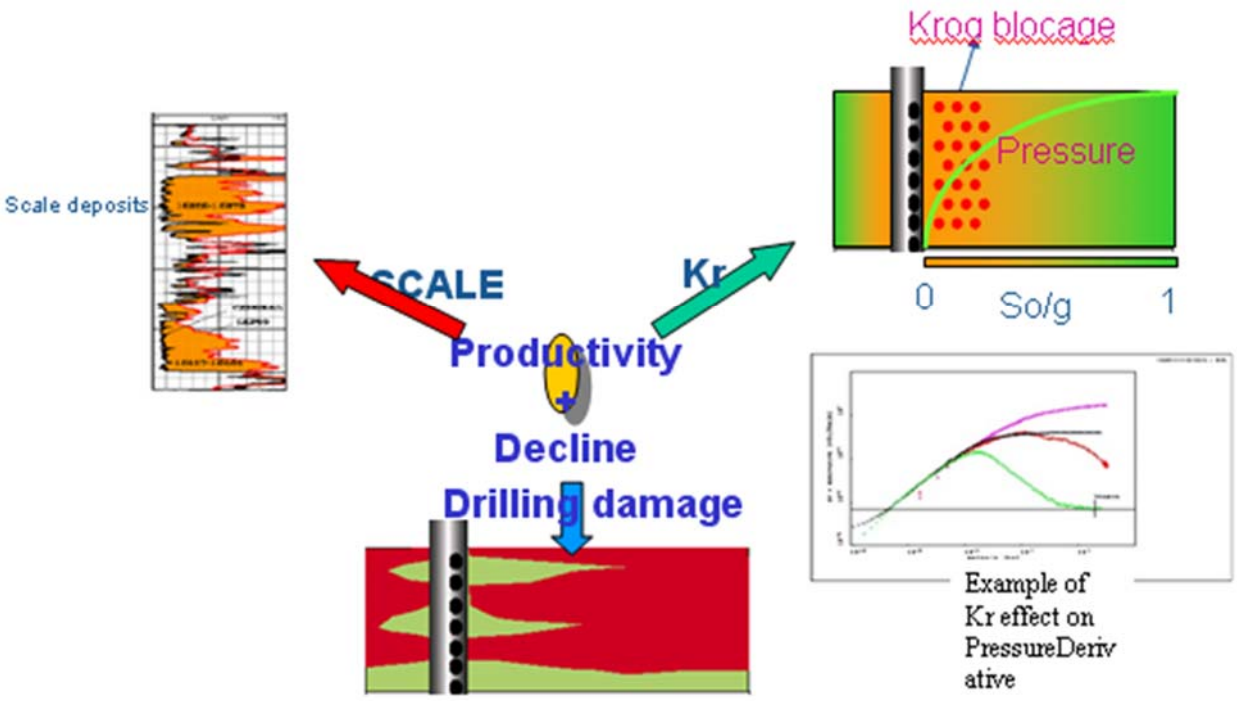


… Typical interpretations

- **Early time (near well bore effect):**
  - Wellbore storage
  - Skin
  - Fractures, HW, PP…
- **Middle time (reservoir behavior):**
  - Infinite acting radial flow:
    - Homogeneous Kh/Mu
    - Heterogeneous, 2phi, 2K, composite, etc.
- **Late time (boundary effects)**
  - Constant pressure
  - Outer boundaries…

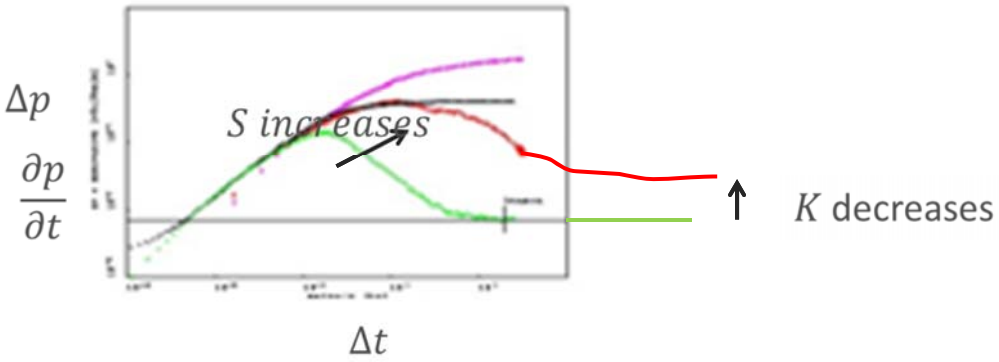
Example: formation properties monitoring

- Reservoir Monitoring (example of possible causes to productivity decline)



K and Skin impact

- **Clay swelling**
- **Fine mobilizations**
- **Impacts on the formation properties:**
  - Impact on near well bore >>>Skin
  - Impact in the reservoir >>> K(permeability)
  - Can be seen and quantified from well test

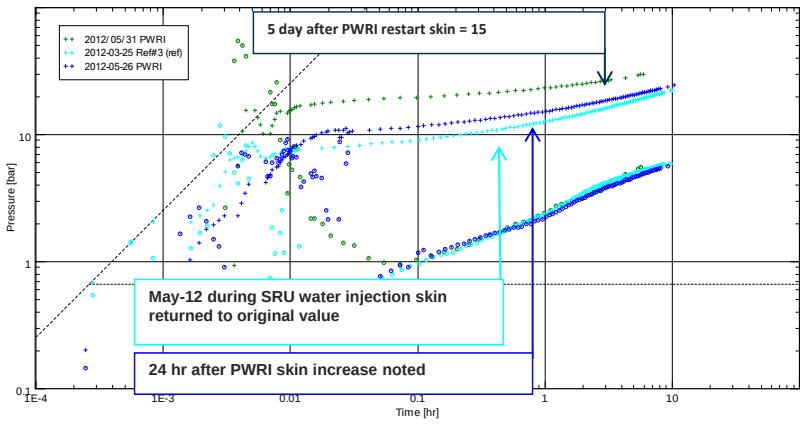


Example

Short-term and long-term impact on injectivity

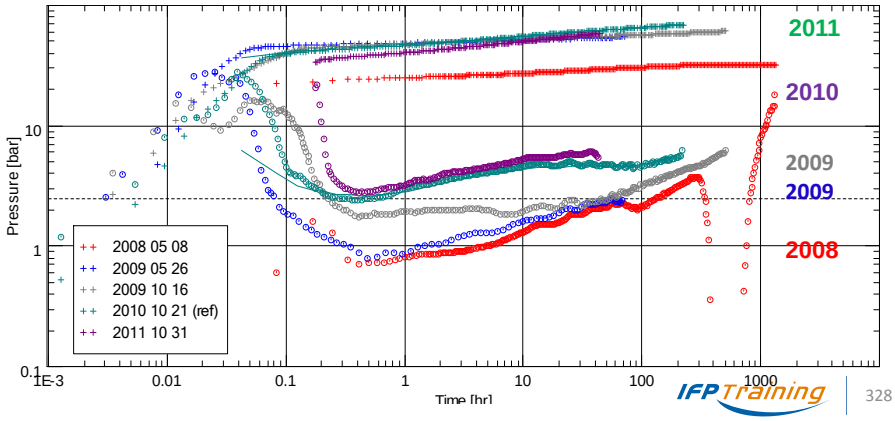
Well1: PWRI 5 days in May-12

Mechanical Skin initial 2
Mechanical Skin PWRI 15
II Reduction 185 → 140 sm3/d/bar **-20%**



Well2: PWRI 2008-2012

Mechanical skin x3
Permeability thickness x0.35
II Reduction 120 → 60 sm3/d/bar **-50%**



Testing / Field operations measurements

WHEN ?

1. At start-up to confirm potential vs expectation
2. **During the field life to provide data on the evolutions of reservoir characteristics**

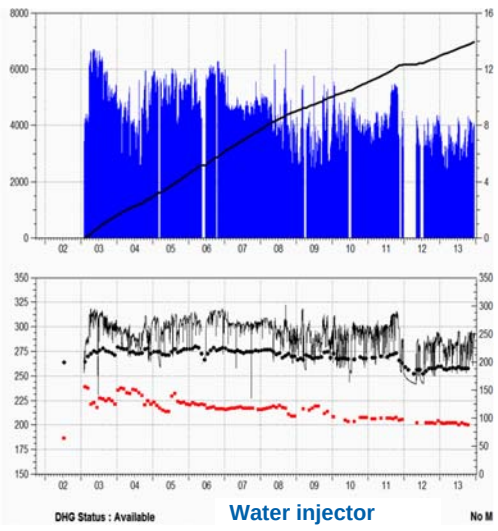
- Tests
  - Pressure Build up, multi-rate tests, interferences…

- **Production parameters**
  - Rates, GOR, BSW, THP, THT, (BHP?), fluids (Hc/Water, chemical analysis...)

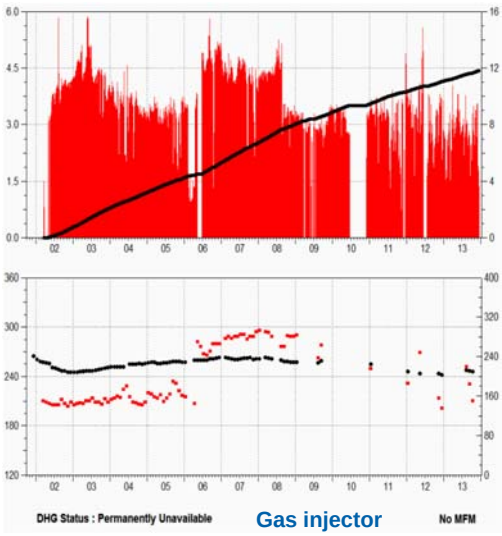
- **Production parameters and metering means**
  - Rates, GOR, BSW (test separator, Multi Phase Flow Meter, ..)
    - Allocation (wells, reservoir, units, …)
    - Model history matching (needs validated production data…)
    - …
  - THP, THT, (BHP?) (sensors –gages, optic fibers, .. at different location)
    - Pressure follow-up
    - Downhole control: drawdown producers Well/reservoir, completion integrity
    - Downhole control: injection pressure control – Pmax, …, avoid fracturing and formation/seals integrity
    - Network matching (VLP curves, pipe Dp matching, subsea devlpt, …)
  - Fluids (Hc/Water, chemical analysis...)
    - Characteristics changes
    - Water (formation vs injected)
    - Water tracers analysis, …
  - Other: sand detection (wells completion integrity)

Production monitoring during field operations

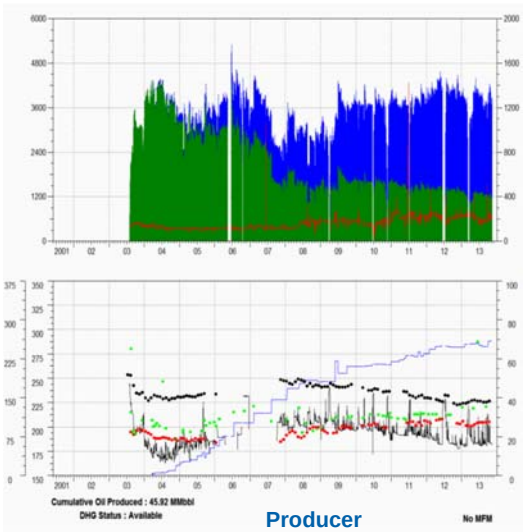
- Reliable devices: test separator, Multi Phase Flow Meter, …
- Reliable sensors –gages, optic fibres, .. at different location
- Reliable process of allocation (wells, reservoir, units, …)



Water injector



Gas injector



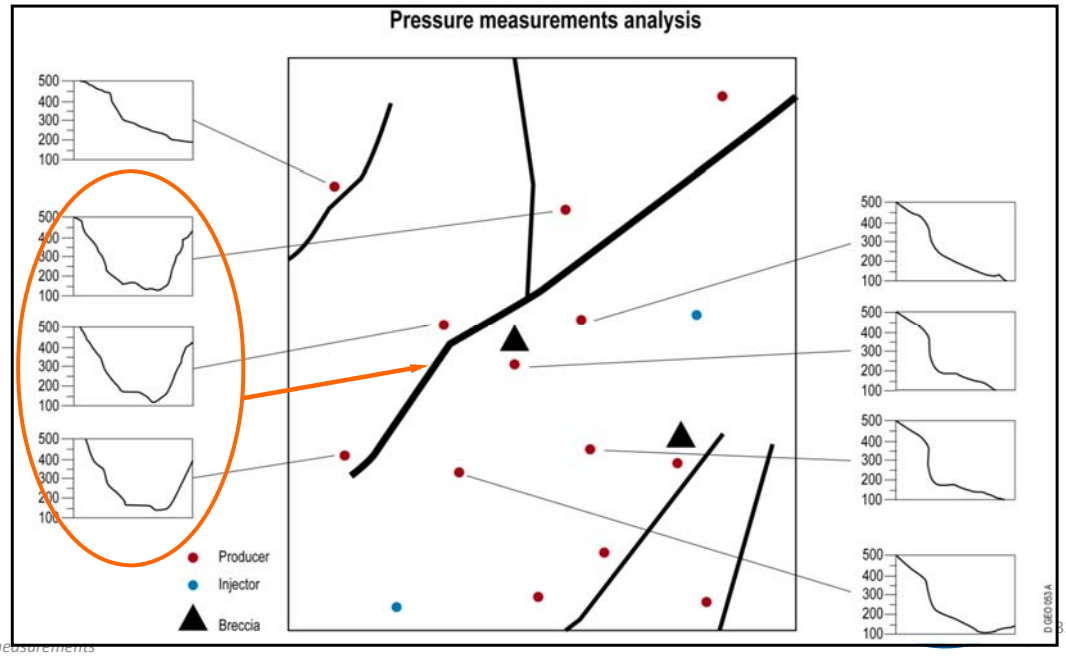
Producer

Pressure measurement analysis

Identification of dynamic barriers with pressure data

- Different pressure behaviors between 2 groups of wells define a permeability barrier that can be correlated with the presence of a conductive fault
- Note: GOR and water break-through data can also be used to determine preferential trends of hydraulic flow

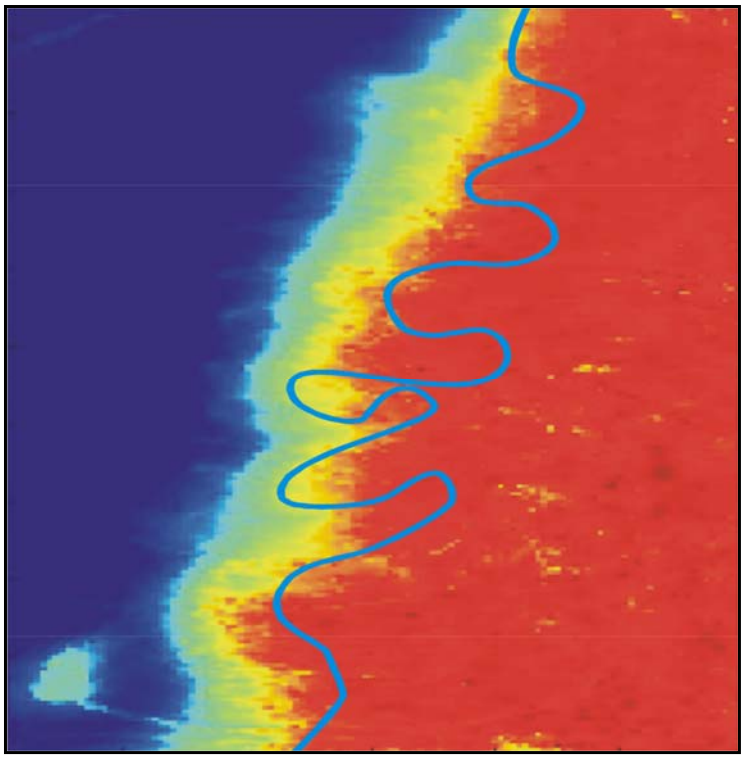
P° increase due to water injection conducted by fault



Breccia = fractures on cores

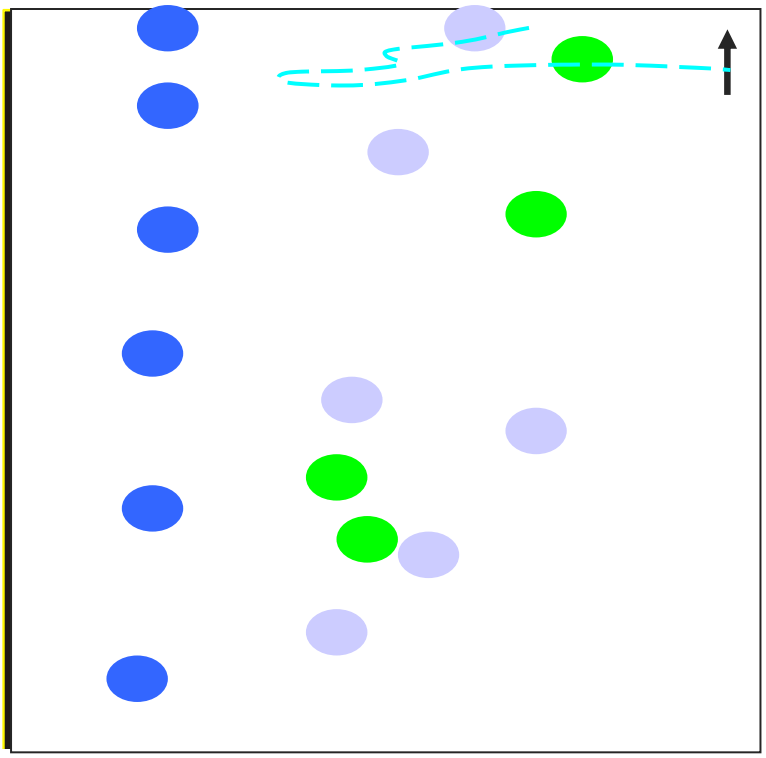
Production history and watercut analysis

Break-through analysis for fluid flow anisotropy detection



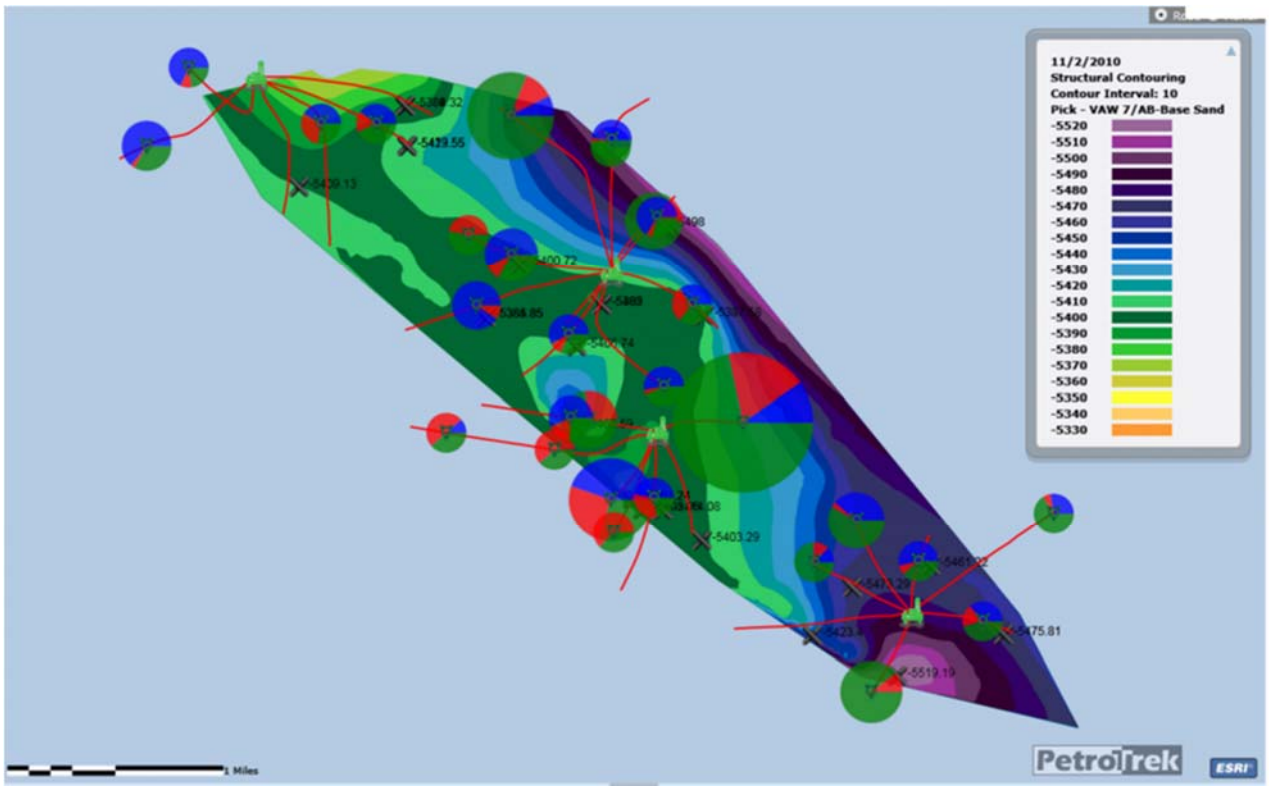
Ghawar field (Saudi Aramco)

Fracture swarm identification



- Injector
- Dry oil producer (no water cut)
- Wet oil producer (water)

Bubble map: oil, gas and water





Data acquisition and monitoring

6. 4D seismic

Additional information on the reservoir

- **Reservoir = a rock with fluids in pores (geophysical definition)**
  - Rock characterization
    - 3D seismic
    - Amplitude maps & Seismic facies analysis
    - Inversion & Modeling
  - Fluid detection
    - AVO – AVA
    - DHI
    - Amplitude anomalies
    - 4D: fluid monitoring

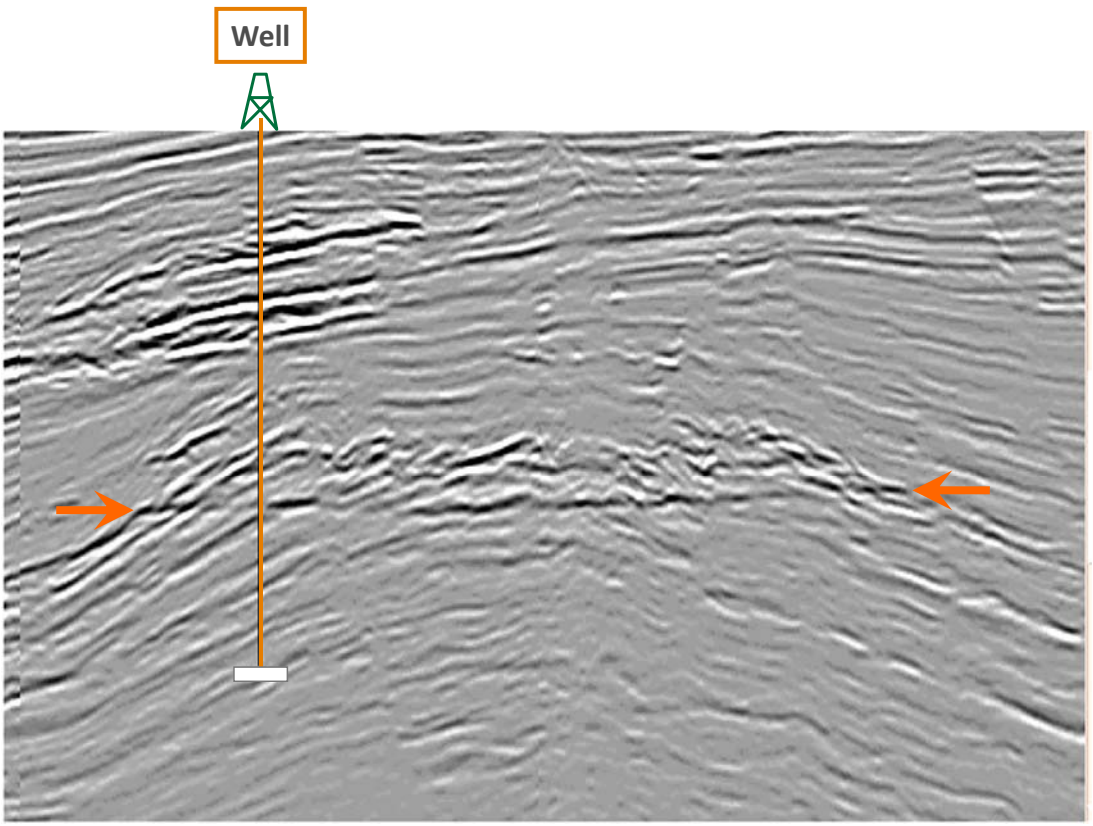
Direct hydrocarbon indicators (DHI)

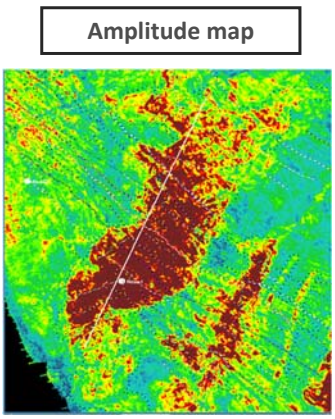
Different types of DHI

- Flat spots: sub-horizontal contrast due to fluid contact
  - Dim spot: amplitude drop
  - Bright spot: amplitude boost
- Pull-up/Pull-down: wave propagation velocity variation due to either gas effect, strong lithology contrasts, or important porosity changes
- Polarity inversion: signal transformation due to the presence of different fluids at the reservoir top (application: fluid production monitoring)
- Chimney effect: blurred reflected signal above a hydrocarbon-bearing structure (vertically)

Qualitative analysis of amplitudes

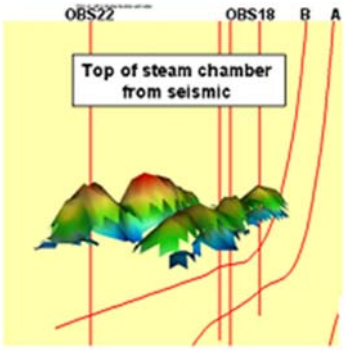
"Flat spot" on map & section



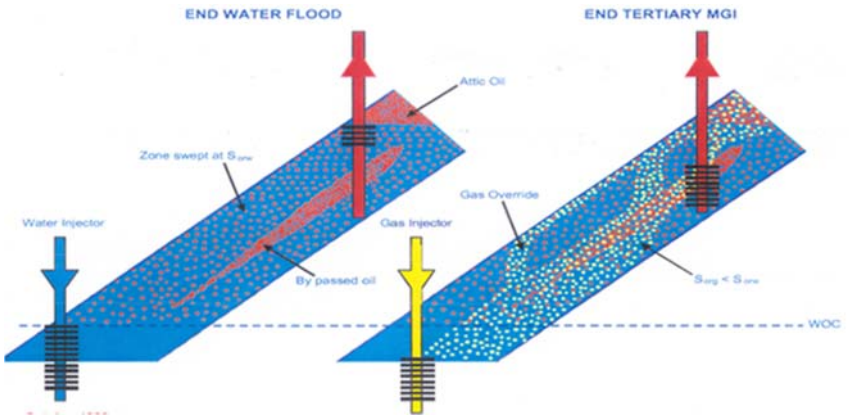


W. Beydoun *et al.*, 2000 - Courtesy TOTAL

What is expected from 4D seismic?



- **4D seismic gives additional information about:**
  - The communication across faults
  - Water and gas migration paths (Saturation and bypassed oil)
  - The change in fluid contact levels
  - Pressure compartmentalization
  - Temperature changes



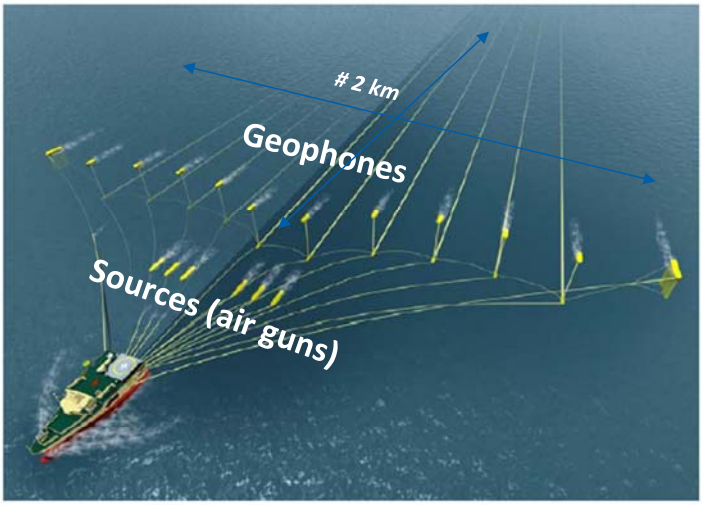
- **It is an input to geological and reservoir simulation models and contributes to production and injection optimization**

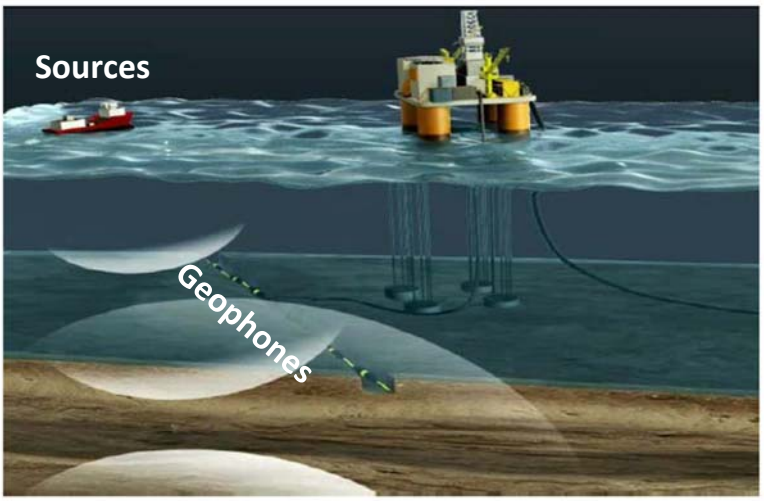
Examples of 4D seismic uses from Norway

A pioneer

- **4D seismic works best when porosity is rather high (~ 30%). This is what we often encounter in Norwegian fields.**
- **The strategy for Norway is to recover a maximum of hydrocarbon fluids.**
- **The best tool to optimize hydrocarbon fluid recovery is the reservoir simulation models properly calibrated with historical data, which is the monitoring data.**
- **Therefore, the Norwegian Petroleum Authorities have set 4D seismic acquisition as a priority for most fields.**
- **This is the reason why Norway has become the 4D experimental lab at Full Field scale.**
- **As usual, Norwegians do not keep secret their data and a lot of them are available on internet sites. We thank Statoil and the NPD for sharing their (costly) data with us.**

Conventional seismic vs permanent seismic offshore



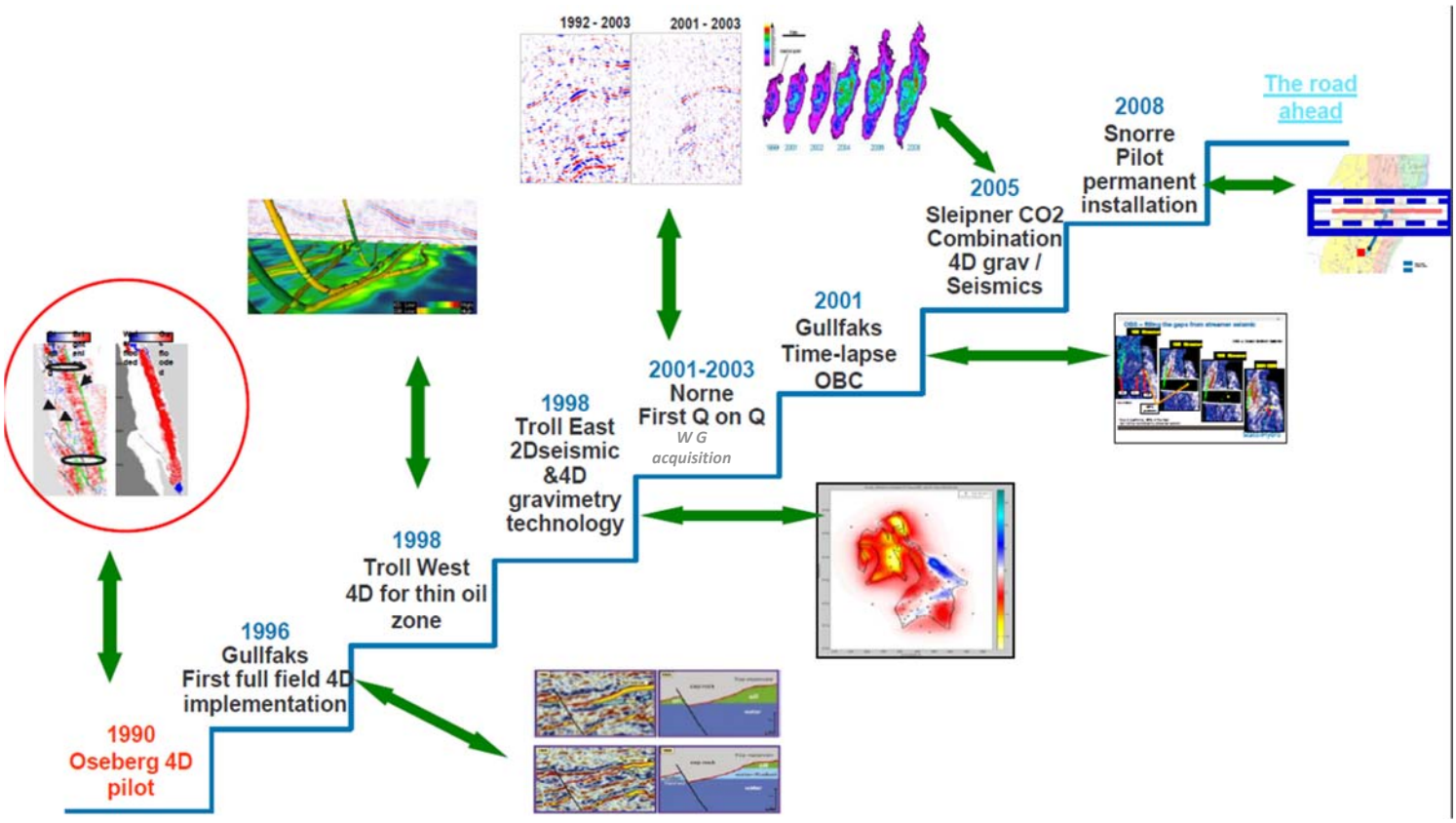


Conventional seismic acquisition every second to third year

Permanent Seismic installation
Seismic acquisition 1-2 per year

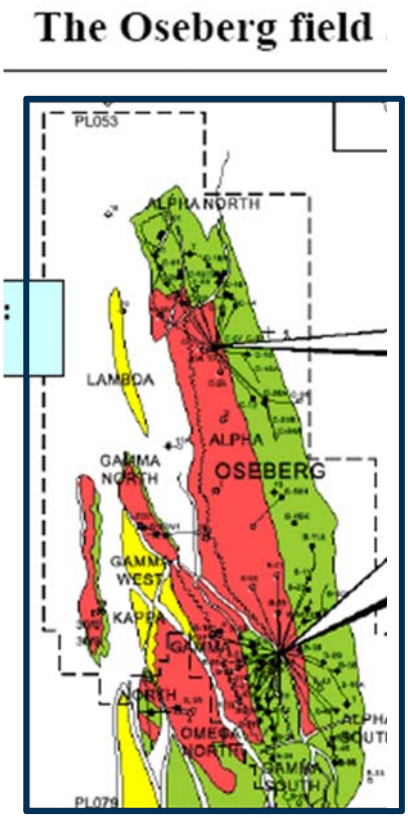
Ocean **B**ottom **C**able/**S**eismic

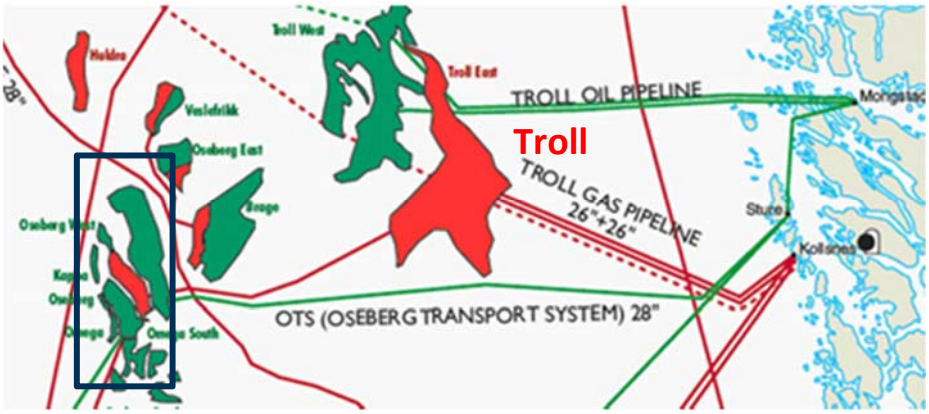
Norway / Two decades of 4D geophysical developments



Oseberg field: from 4D pilot to geophysical reservoir monitoring

A gas gravity displacement field case





Oseberg field: from 4D pilot to quantitative GRM

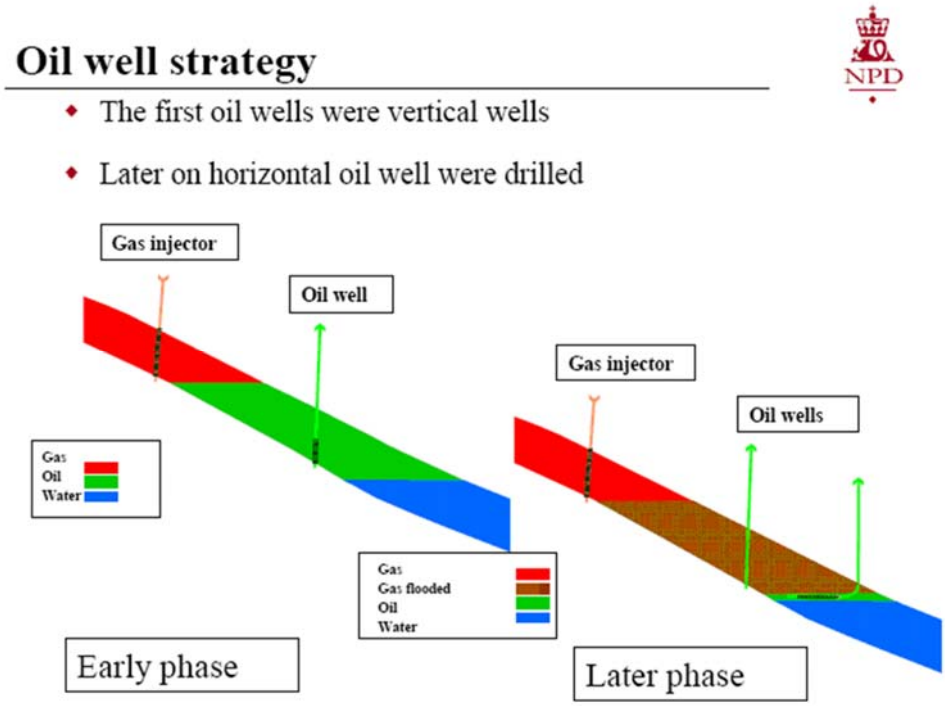
A gas gravity displacement field case

- **The Oseberg field development plan has been revised several times**
  - Initial FDP in 1983 (discovery 1979) was based on water injection mainly
    - even studies were showing interest –better residual saturation- of gas injection
  - Discovery of giant Troll gas field in 1983 led to a FDP change with gas injection / gravity drainage
  - The regular oil production at PF B was initiated end 1988, and at PF C on Sept 1991
    - The wells were initially sub-vertical and located fairly high in the initial oil zone due to the uncertain aquifer response during pressure depletion;
  - The well strategy was altered in 1992 with the drilling of the first horizontal well.
    - At the end of May 1997, 28 horizontal wells had been completed in the Oseberg field located some meters above OWC
    - The multi-lateral wells are sidetracks from predrilled conventional wells
    - Initially non-economic areas/reservoirs were developed

Oseberg – Evolution of field development plans

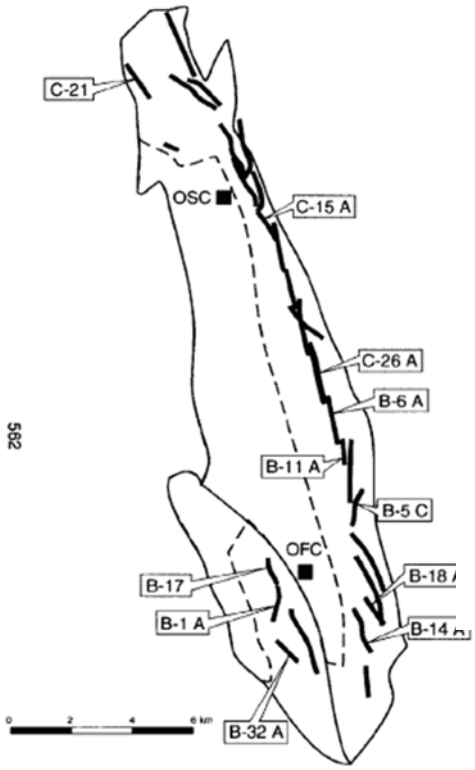
Well Strategy:

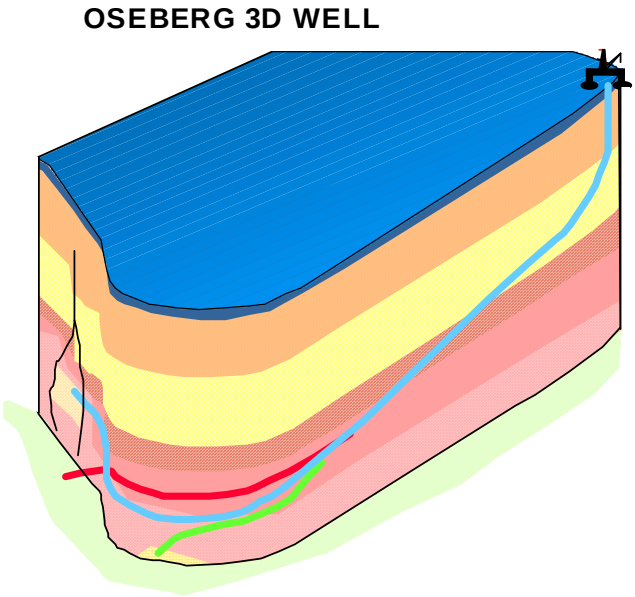
- The Oseberg well strategy has moved from initial vertical (conventional) wells towards horizontal and multi-lateral wells .



Oseberg - History of field development plans

Horizontal Wells





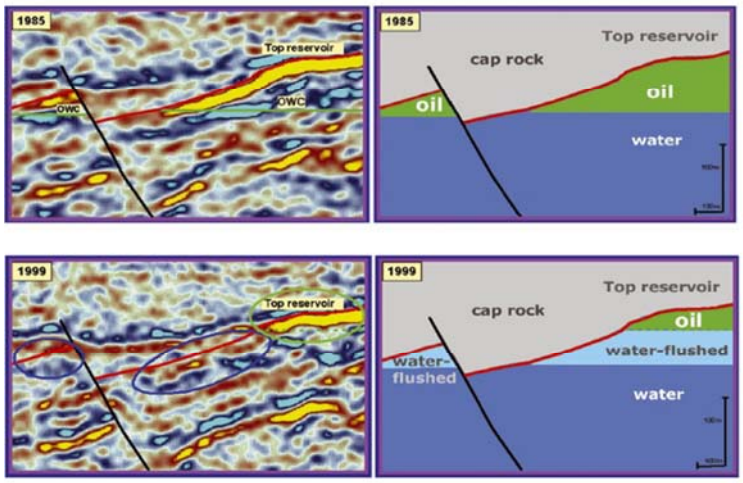
Reservoir monitoring strategy result

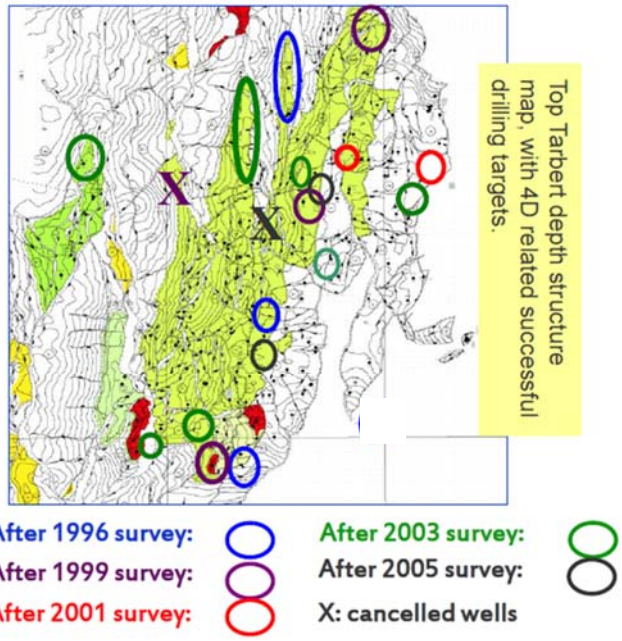
- **With the aim at controlling the stability of the gas front with the maximization of oil production rates**
- **The reservoir monitoring has been focused on:**
  - Pressure recordings (RFT at wells, wire-line measurements every 6 months, permanent gauges on some wells)
  - Gas front observations (TDT logging, water tracers, 4D seismic first pilot in Norway
  - Advanced testing to determine residual oil saturations has also been performed
  - Production logging (Producers H& V, injectors multi-rate).
  - Extensive Laboratories measurements (residual saturation with gas flooding)
- **And continuous modeling update for reserves forecasts / extension development proposals**
- **Recovery factors: #30% (FDP init WI) - #65% (current expectation)**

Gullfaks: full field GRM lab & « cash machine »

Development with water injection

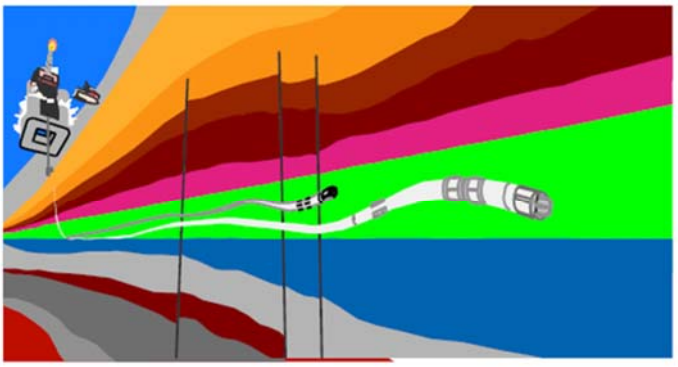
- 19 wells have been placed using input from 4D data
- Produced volume in these wells is ~64 MMBO
  (value creation in excess of 1,0 MMUSD when assuming 50% impact from 4D)

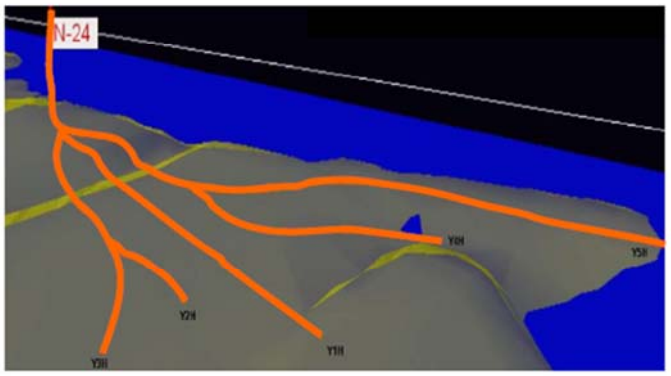




Troll oil rim

- Increases the well length
- Targeting a thinner oil column
- Inflow control device in many wells (ICD)
- 114 horizontal wells and 33 vertical wells

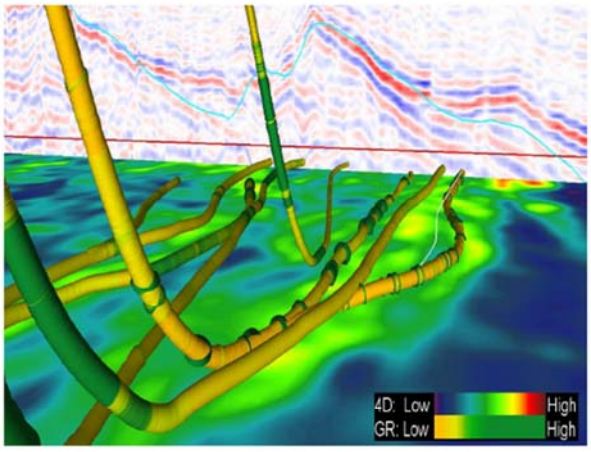




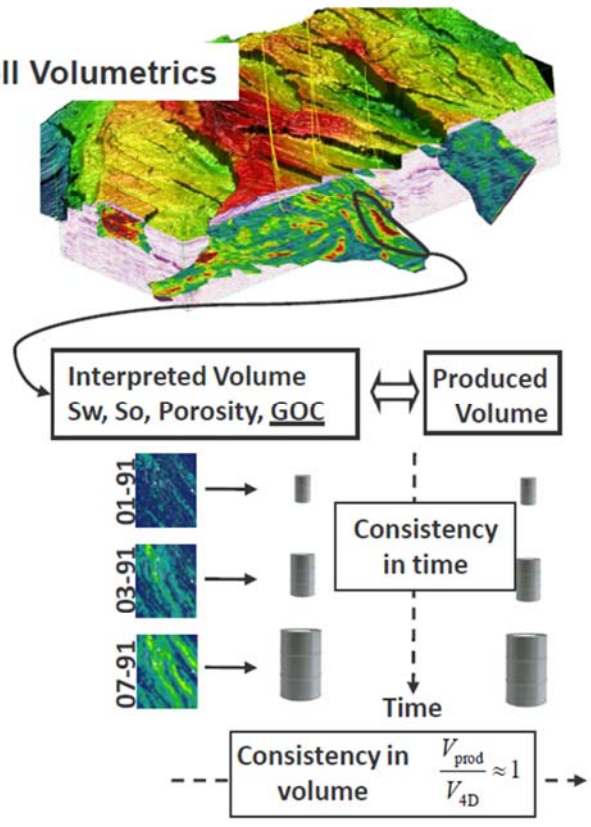
Troll West: success in monitoring thin oil zones

Complex geometry wells thanks to 4D Seismic

Advanced qualitative use of 4D attributes



Troll Volumetrics

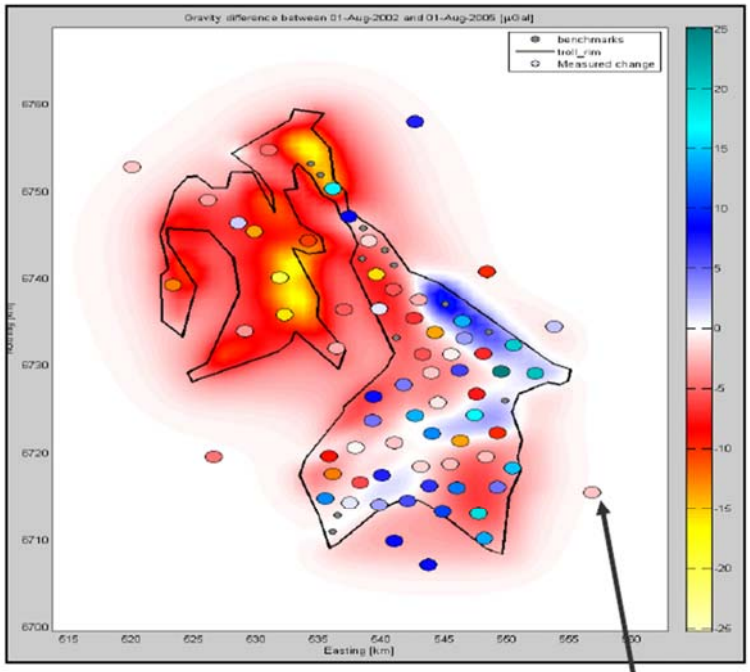


Troll East: extending the GeophResMon toolbox

Gas field produced in with aquifer influx

The time-lapse gravity anomaly :

a smoothed version of the reservoir mass change



Gravity measurement stations

For gravity spatial change evaluation

Monitoring in obs.well

Permanent pressure sensors

Repeated saturation logging

Reservoir compaction

Gravity monitoring

80 seafloor stations

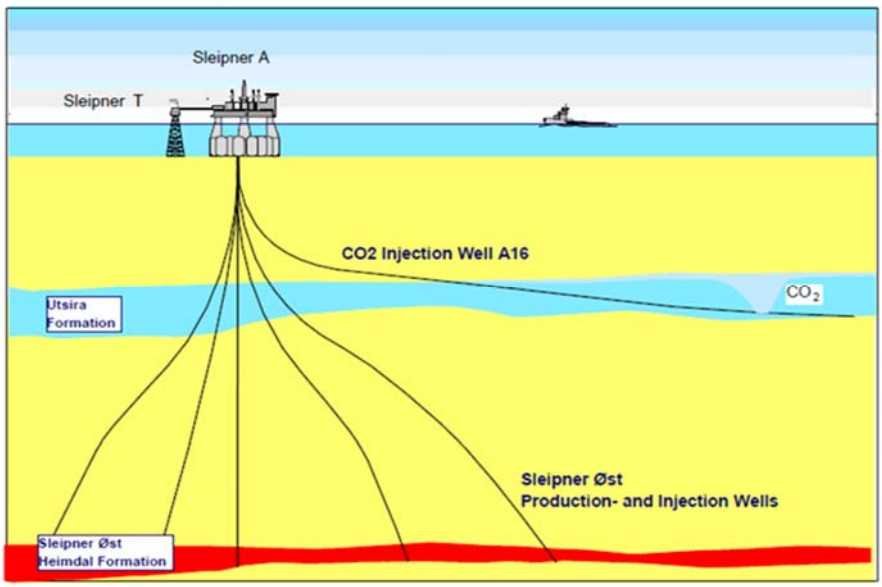
Time-lapse 2D/3D seismic

250 line-km

800 km²

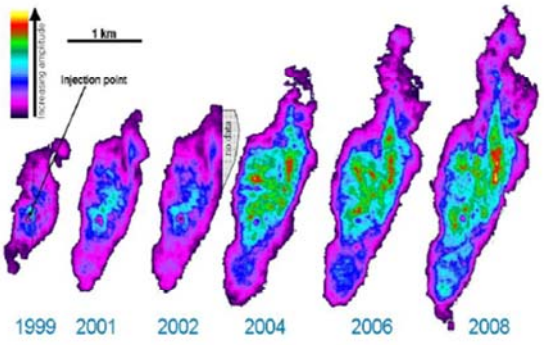
4D Example Sleipner: CO2 injection storage

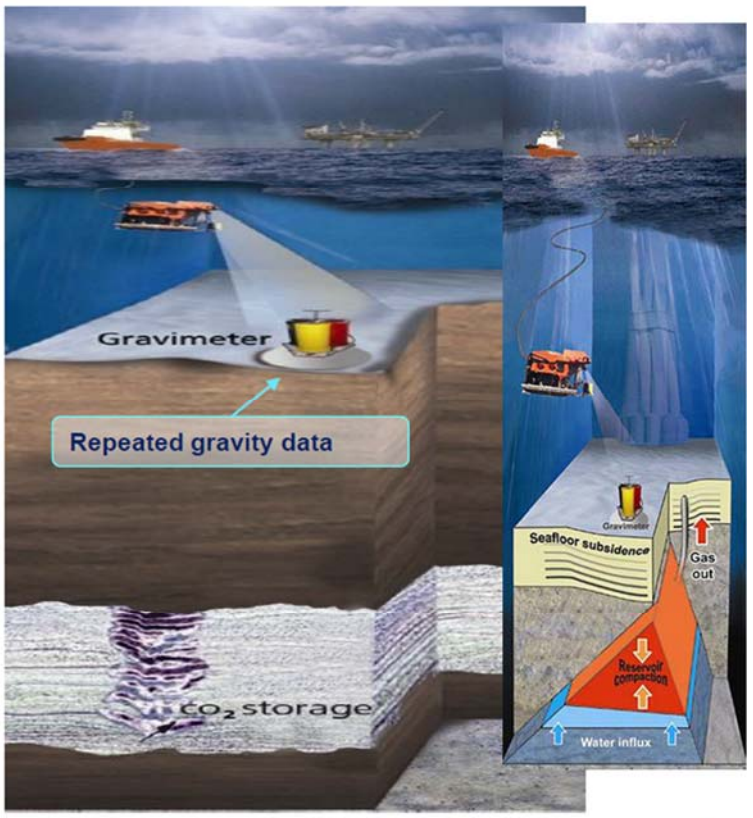
- **To reduce CO2 concentration from 9% to 2.5% (Sale spec.)**
- **CO2 capture method: Amin plant**
- **CO2 storage in an aquifer above the reservoir**
- **1 million tons of CO2/yr since 1996**



4D Example Sleipner: GRM for controlled CO2 storage

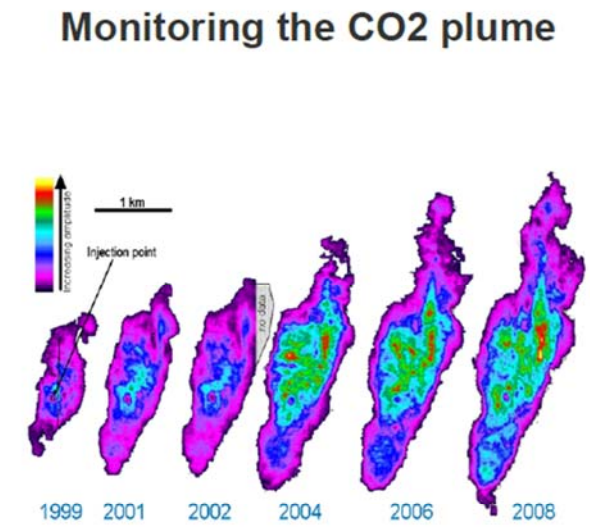
Combination 4D gravimeters & seismic

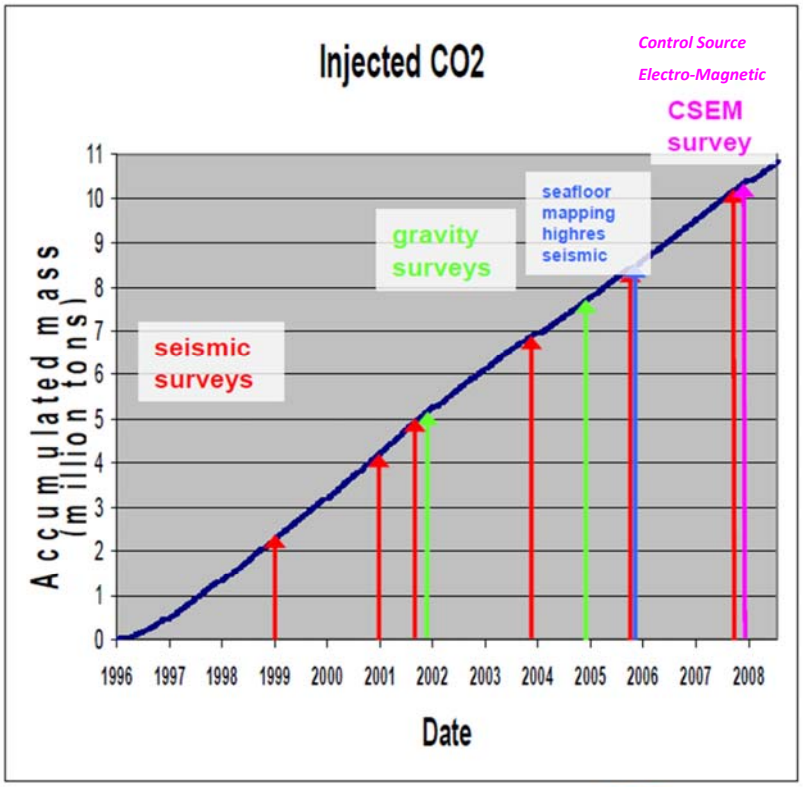




4D Example Sleipner CO2: combining technologies

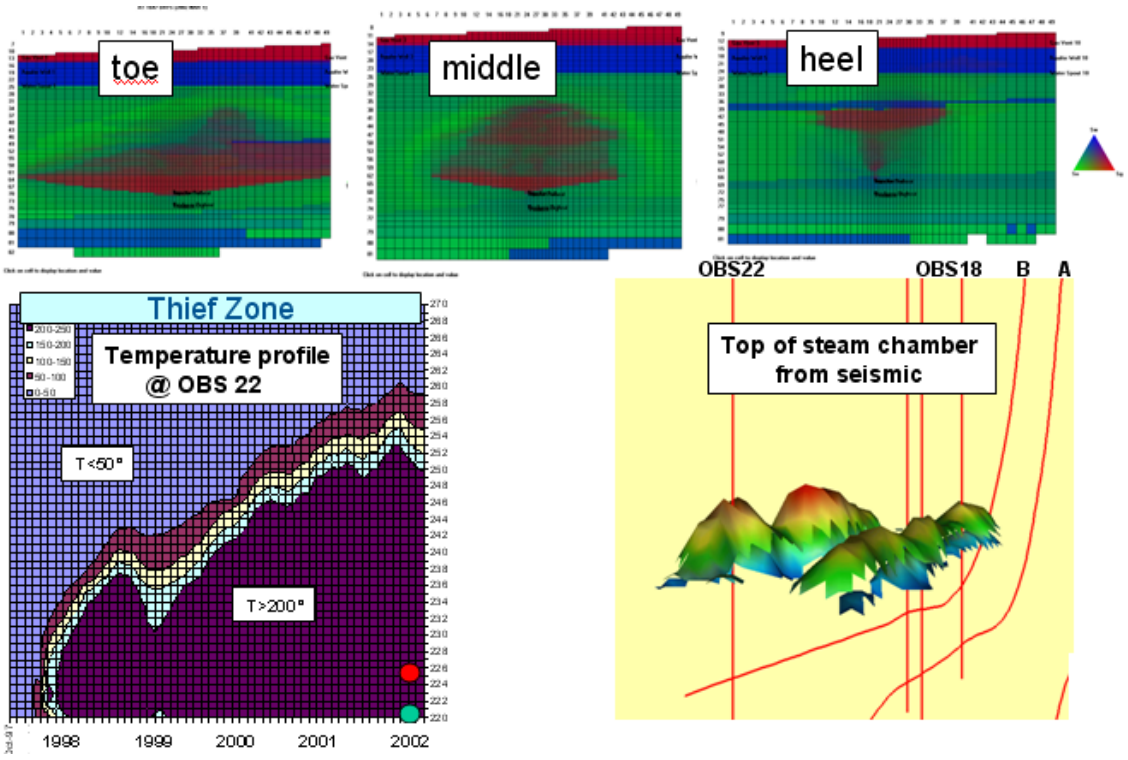
Sleipner CO2: A laboratory for GRM toolbox developments





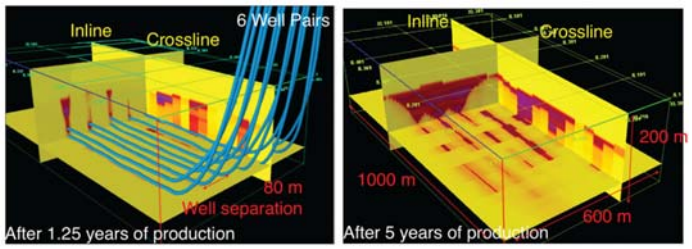
Seismic 4D in steam assisted gravity drainage (not only Norway…)

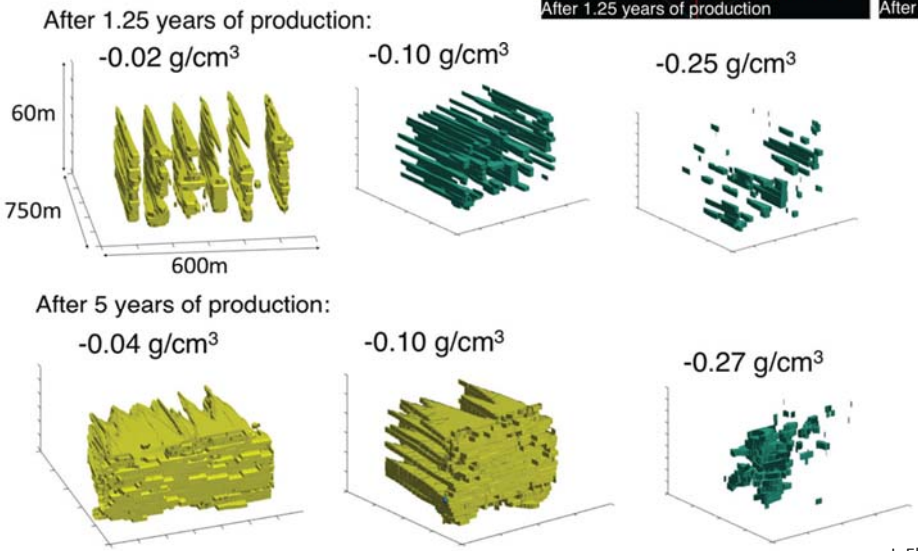
- The case of Surmont: permanent 4D seismic



Seismic 4D in steam assisted gravity drainage (not only Norway…)

- Gravity monitoring in SAGD

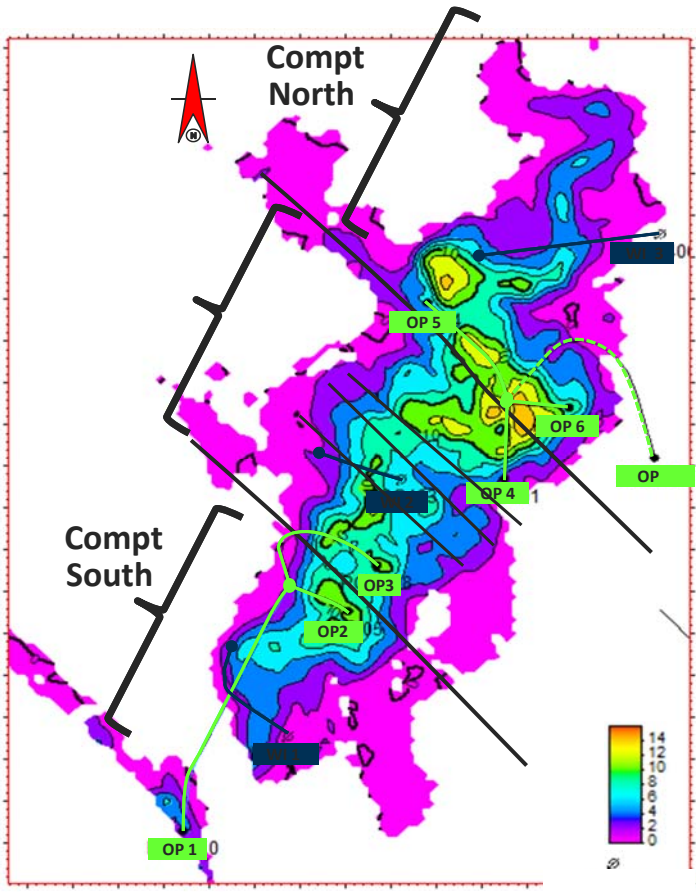




J. Elliott and A. Braun, 2016

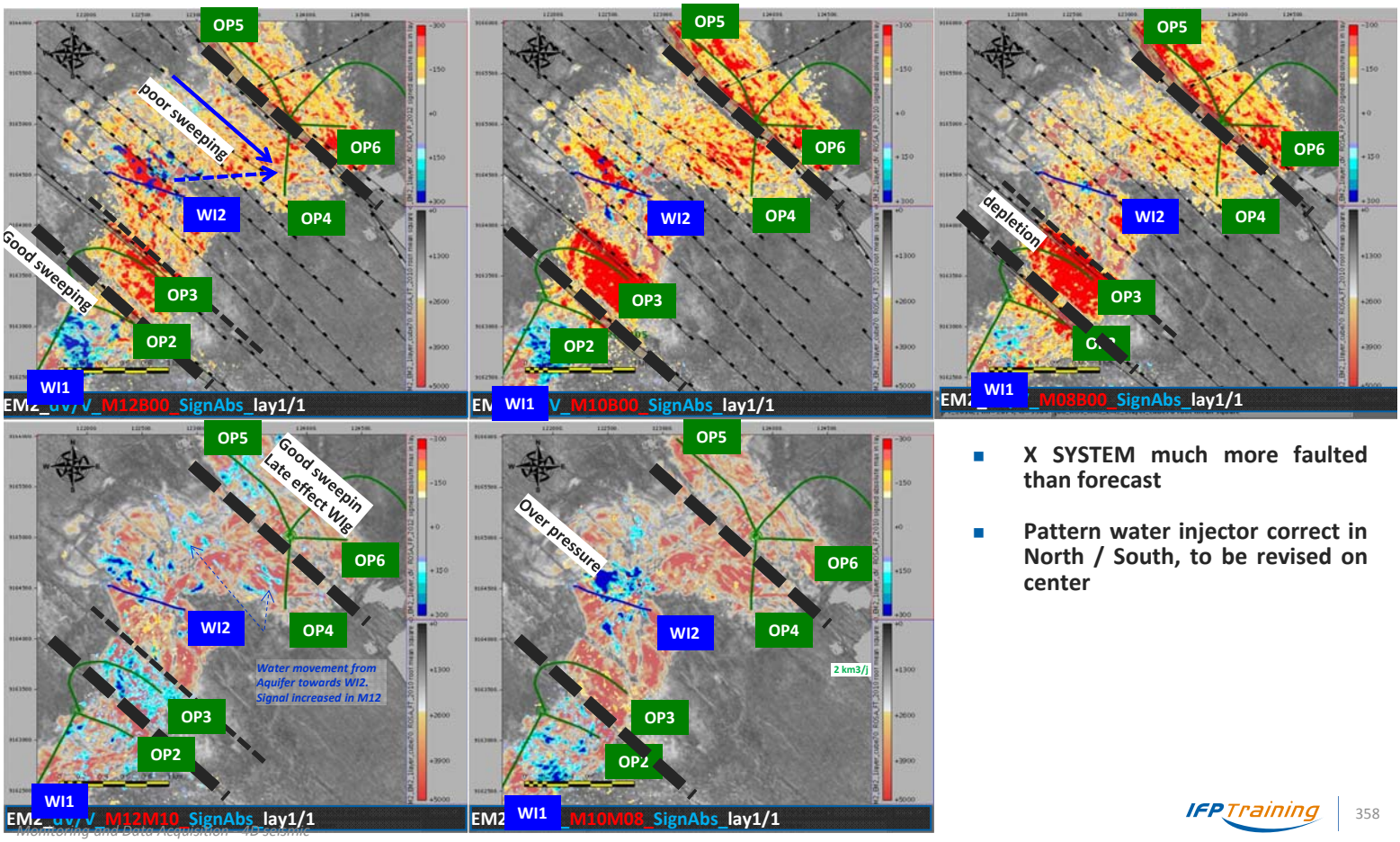
4D SEISMIC example / X system - Compartments

- X SYSTEM Includes “DRAINAGE” compartments
- Pattern water injector (3) / oil producer (6)



4D SEISMIC example / X system - Compartments

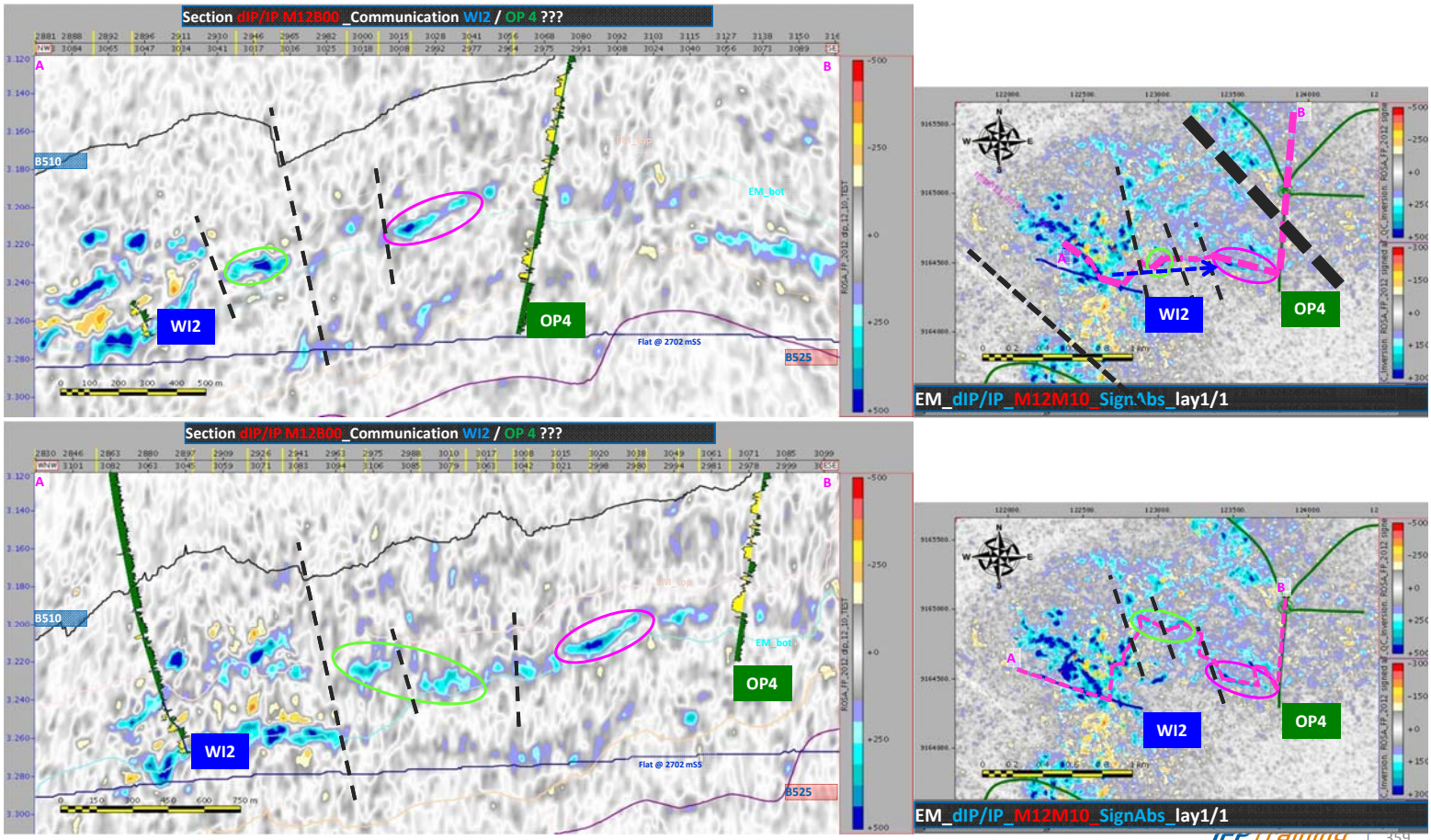
4D maps @ compartement_ EM2 dV/V evolution + RMS Amplitude B2000 -2008/2010/2012



- X SYSTEM much more faulted than forecast
- Pattern water injector correct in North / South, to be revised on center

4D SEISMIC example / X system - Compartments

X system_communication center WI 2 - OP 4 direct ???_ EM 4D dIP/IP_M12M10



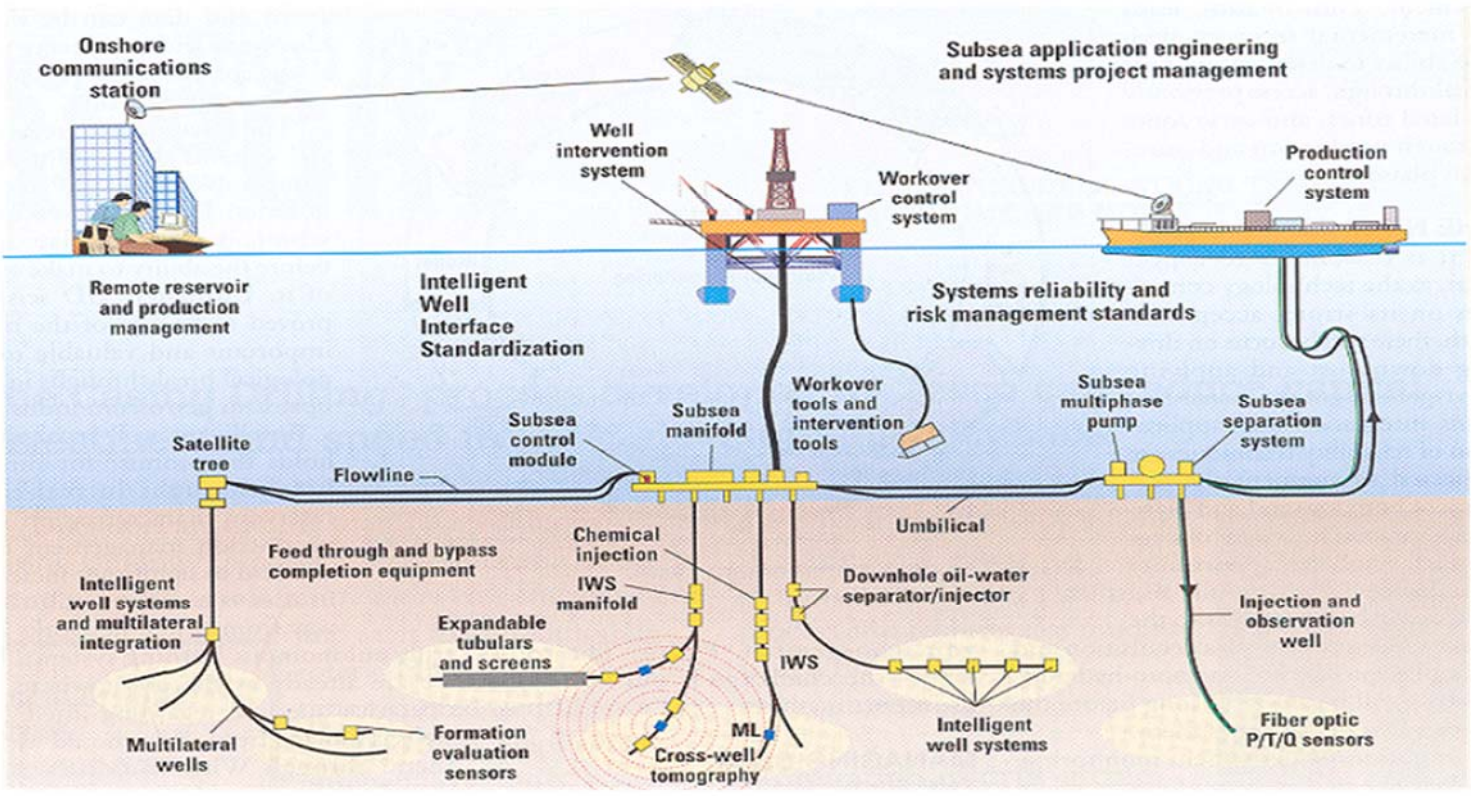
Monitoring well test, production data and seismic

- **Main data gathering in well test: well parameter, reservoir parameters, boundaries**
  - Well parameters: PI, II, Skin, …
  - Reservoir parameters (rock and fluid): PVT, Permeability…, layering
  - Boundaries: Fault detection, fault transmissibility…
- **4D seismic only tool to monitor at field scale**
- **Recommendation on well workover, injection, abandonment…**

Data acquisition and monitoring

6. Examples of development updates
   Conclusion

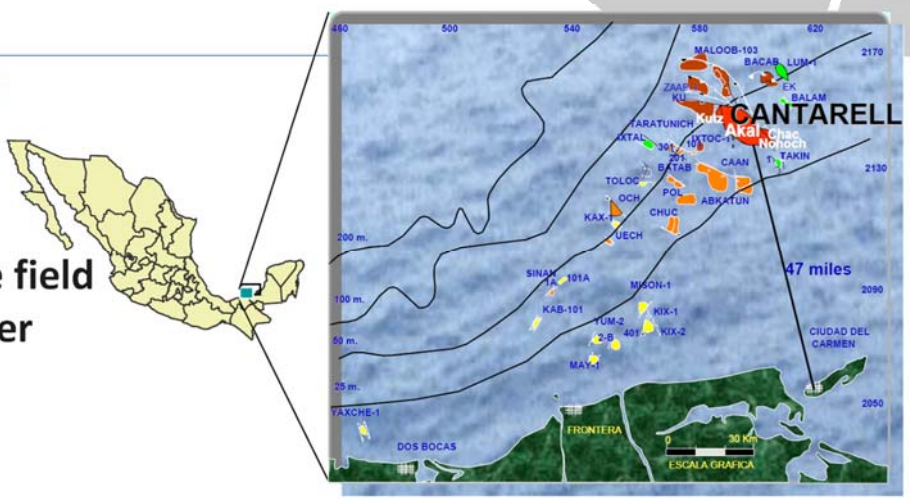
Field producing : well monitoring & integration
… an ideal organization



Immiscible gas njection

Nitrogen injection: case study

Cantarell (Mexico)



- Offshore fractured carbonate field Jurassic, Cretaceous and Lower Paleocene
- Production since 1979
- Plateau of 1 MMBPD 1981-1995
- Initial pressure 3970 psi
- 40 wells in 1981 with 29,000 BPD
- 150 wells in 1995 with 7,000BPD (gas-lift since 1987)
- Phi: 8% (vuges and fractures)
- K: 1 to 3,000md (matrix & fracture respectively)

- Depth: 4,000ft SPE 97385
- API: 22°
- Secondary gas cap generation
- Water breakthrough from vertical fractures
- OOIP: 32 billion SB

Immiscible gas injection

Nitrogen injection: Cantarell (Mexico)

SPE 97385

Nitrogen program

- Nitrogen selected because:
- Availability, cost, handling infrastructures, environmental issues and Safety.
- Cost: 0,54 USD/MSCF against 2.66USD/MSCF of natural gas injection
- Injection of 1.2 BSCFD

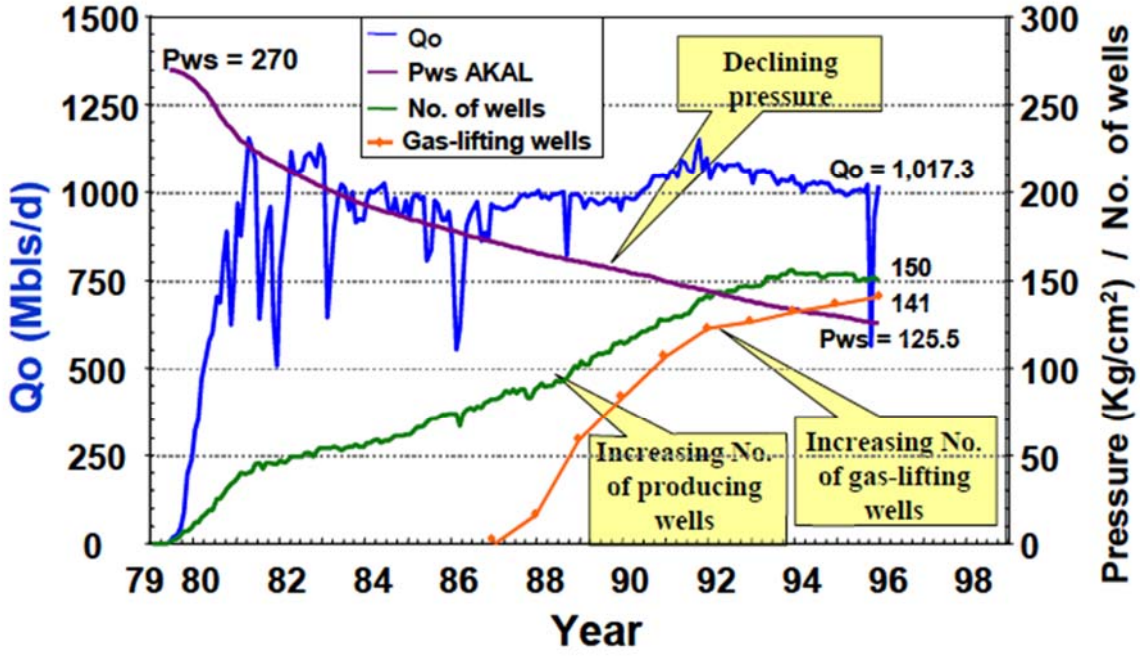
Monitoring program

- Pressure monitoring in 10 wells in the gas cap, oil column and aquifer
  - Very short transient flow regime and then pseudo steady state extremely high transmissibility in this section of reservoir (Akal)
- Nitrogen concentration monitoring
  - Concentration in gas-cap and in oil prior to production
- Gas-oil contact monitoring

Immiscible gas injection

Nitrogen injection: Cantarell (Mexico)

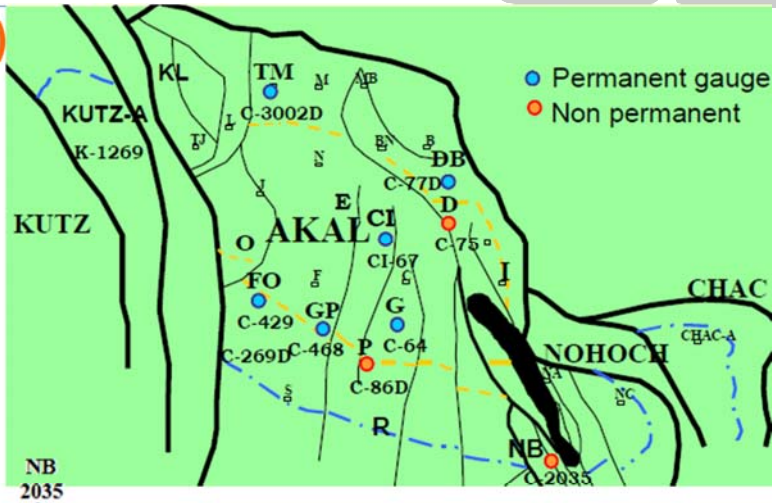
Production history of Cantarell

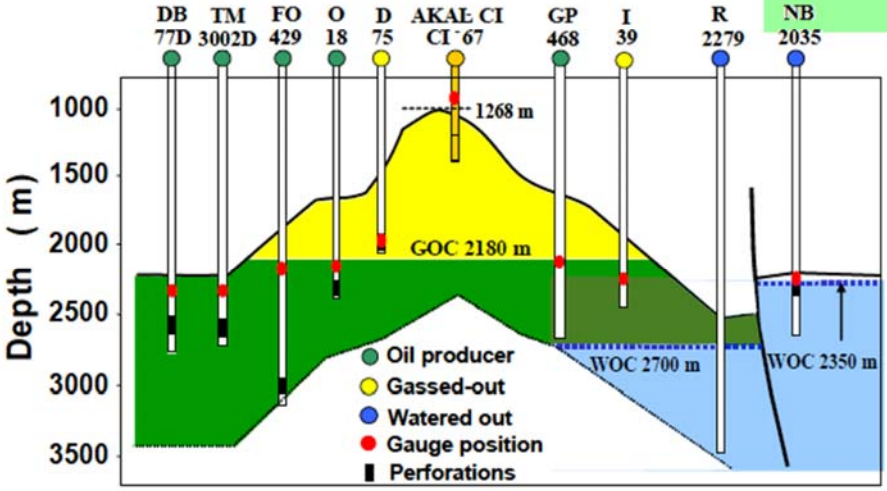


Immiscible gas injection

Nitrogen injection: Cantarell (Mexico)

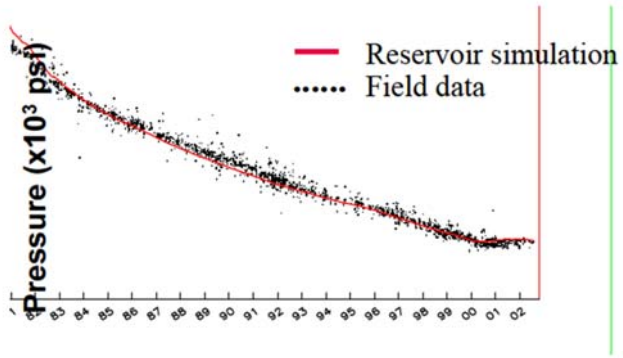
Location of the monitoring wells

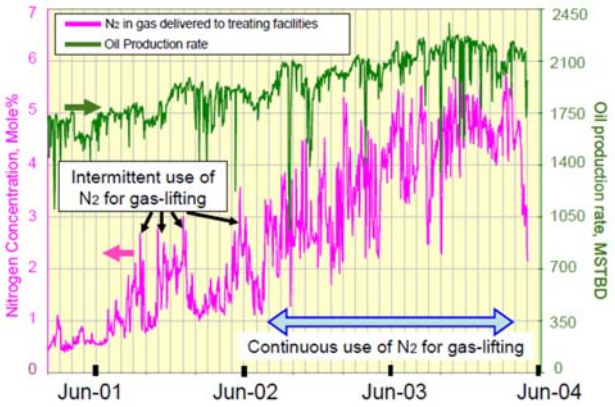


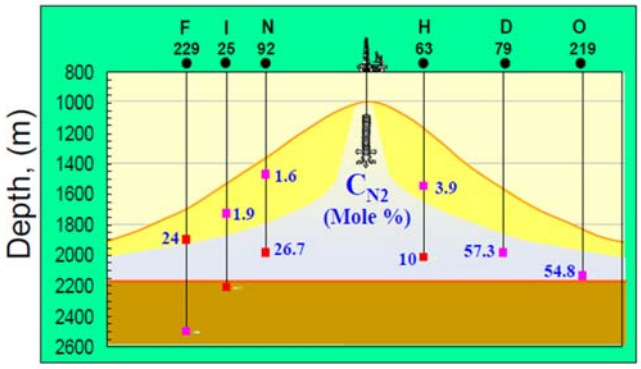


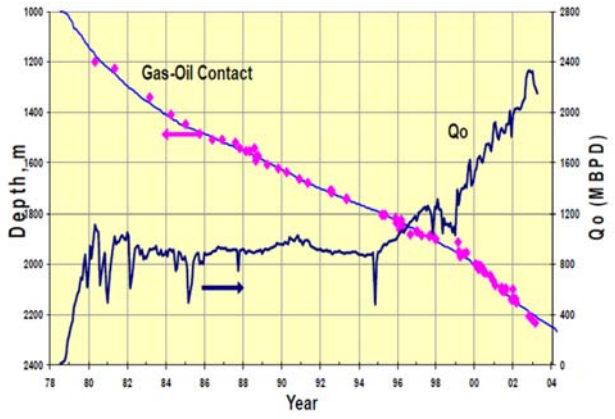
Immiscible gas injection

Nitrogen injection: Cantarell (Mexico)





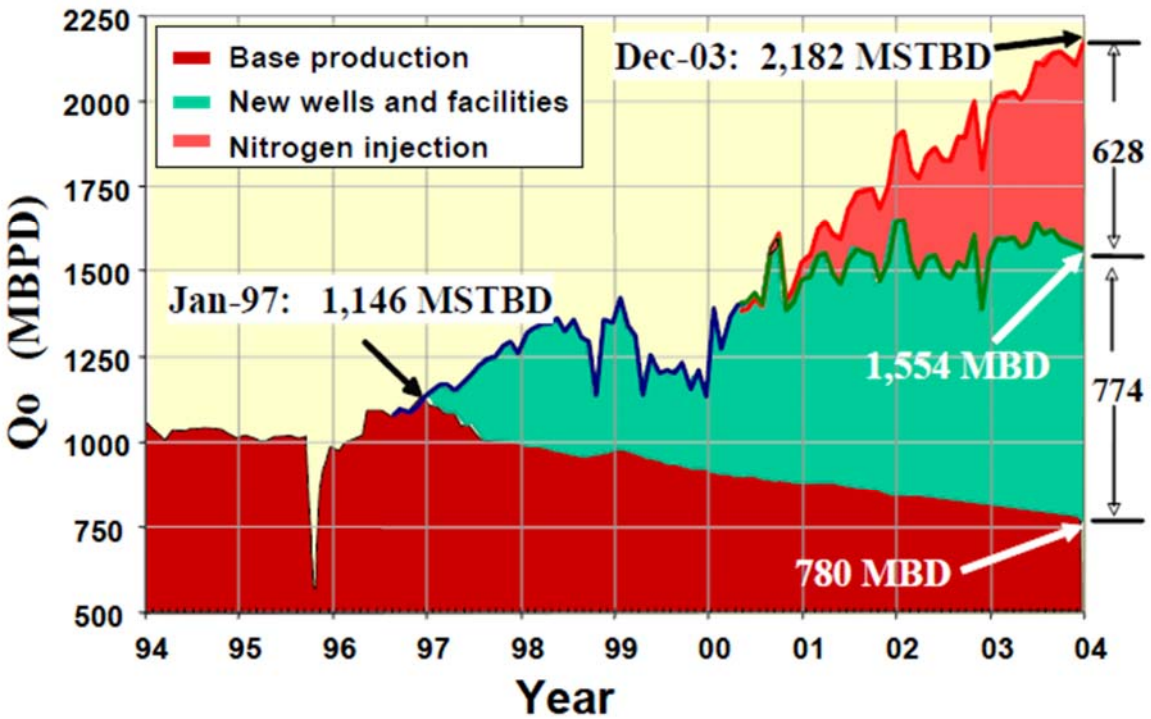




Immiscible gas injection

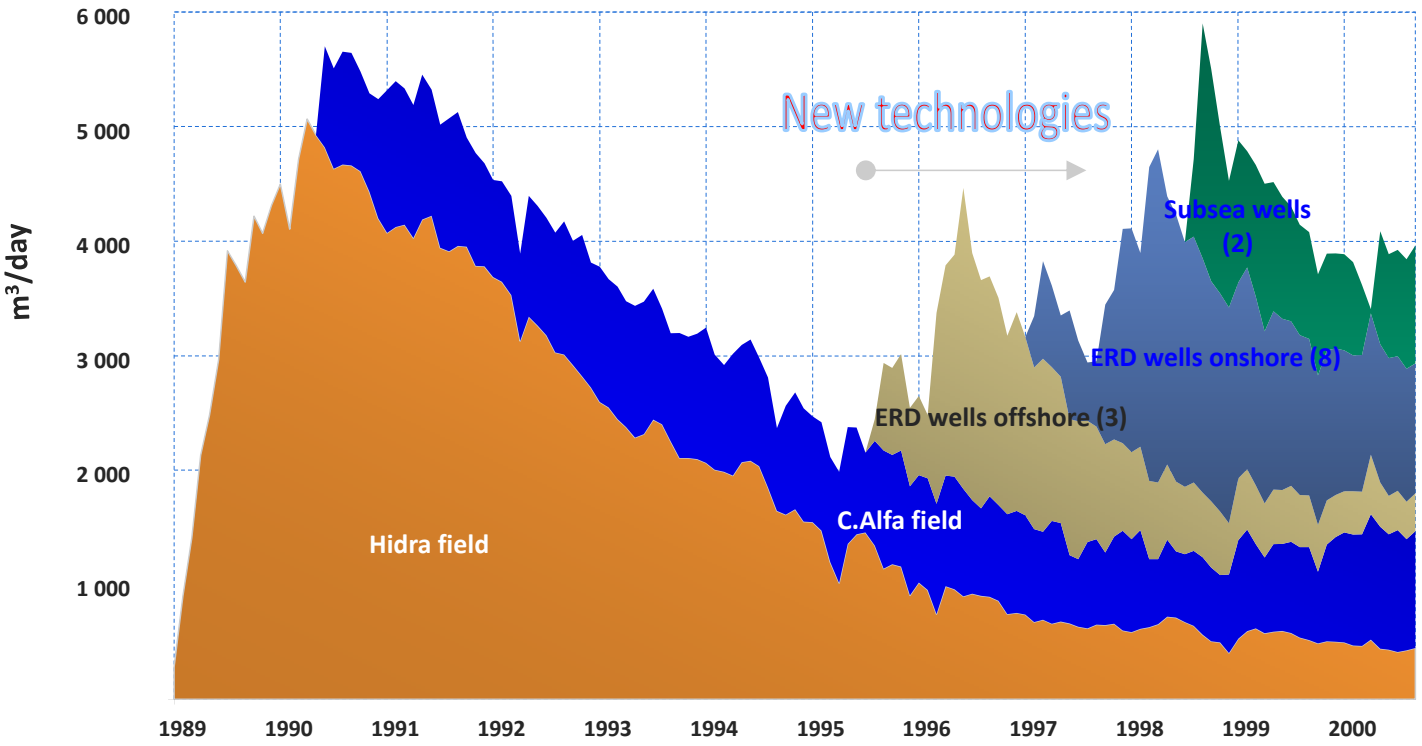
Nitrogen injection: Cantarell (Mexico)

Share of nitrogen injection in production

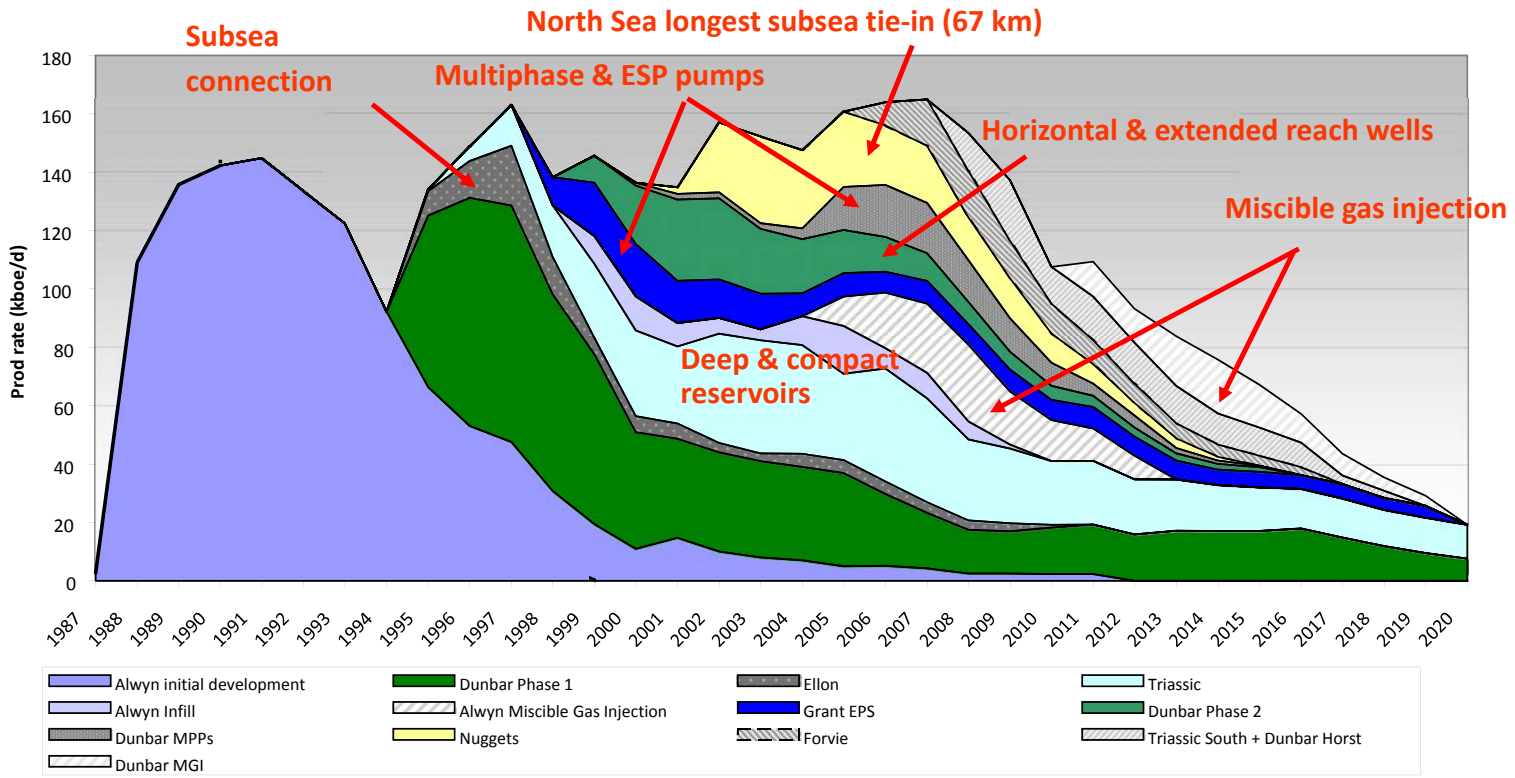


Example: impact of extended reach drilling

Tierra del Fuego - Argentina



Example: Alwyn, a multi-challenge mature field



Some conclusions…

- **Imagination and innovation can help to:**
  - Prevent decline
  - Increase reserves
- **Monitoring is a necessary tool to feed reservoir management with aim at improving field knowledge … stimulate imagination & innovation**
  - It stands from the beginning (exploration) to the end (production & abandonment) of the field life (*initiated in the first Reservoir Management Plan, updated in following RMPs and PREMONITs*)
  - .. The more anticipation on monitoring, the better its impact on improvements (particularly in tough conditions)
  - 4D seismic is a powerful and full scale monitoring device (*when possible*)

Notes

Assessment of reservoir uncertainties

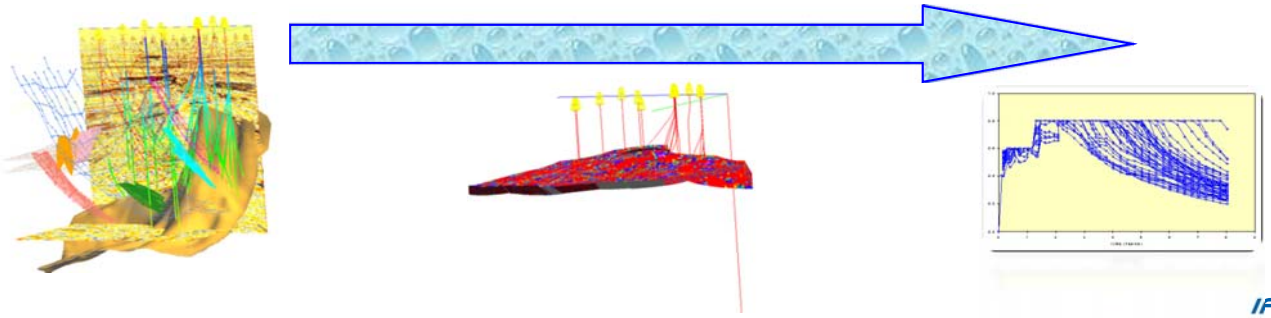


Assessment of reservoir uncertainties:

Training objectives

At the end of this section, you will know:

- **Why it is fundamental to evaluate uncertainties**
  - Mandatory for field evaluation
  - Consequences
- **Practical methodologies and tools for reservoir uncertainty assessment**
  - Global and spatial Monte-Carlo
  - Experimental designs
- **An Overview of uncertainties through the complete workflow of:**
  - Interpretation –> Geomodeling –> Reservoir simulation



Assessment of reservoir uncertainties

- Risk and uncertainty definition

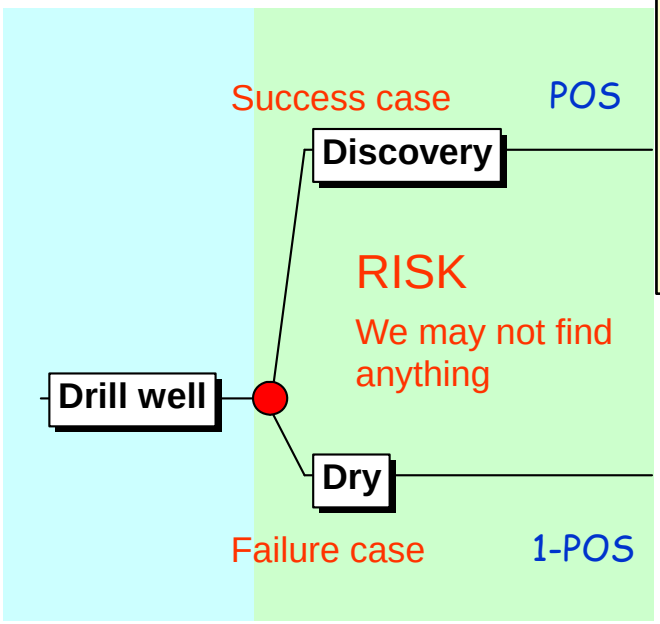


Where does a reservoir engineer encounter risks & uncertainties?

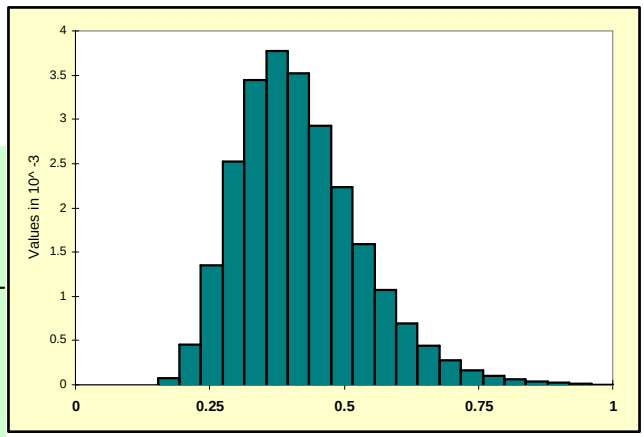
- **Risks and uncertainties are everywhere in EP projects due to the nature of the industry**
- **Exploration:**
  - Try to predict the presence of hydrocarbons in subsurface from indirect/ incomplete/ low resolution measurements and sparse information
  - Try to evaluate the commercial value of the HC discovery with limited data and information
- **Development:**
  - Try to transform a HC discovery into a commercial development project
  - Try to optimize/ increase production from existing field, most of the time with only partial knowledge of field character and behavior
- **Limited budget and time**
- **Evolving industrial and business environment**
- **Evolving technology**
- **Compliance with evolving HSE regulations**

Risks and uncertainties

TWO BASIC NOTIONS



POS = Probability of Success



UNCERTAINTY

Inability to predict exactly the size of the discovery

Will this well find oil?

If it will, how much?

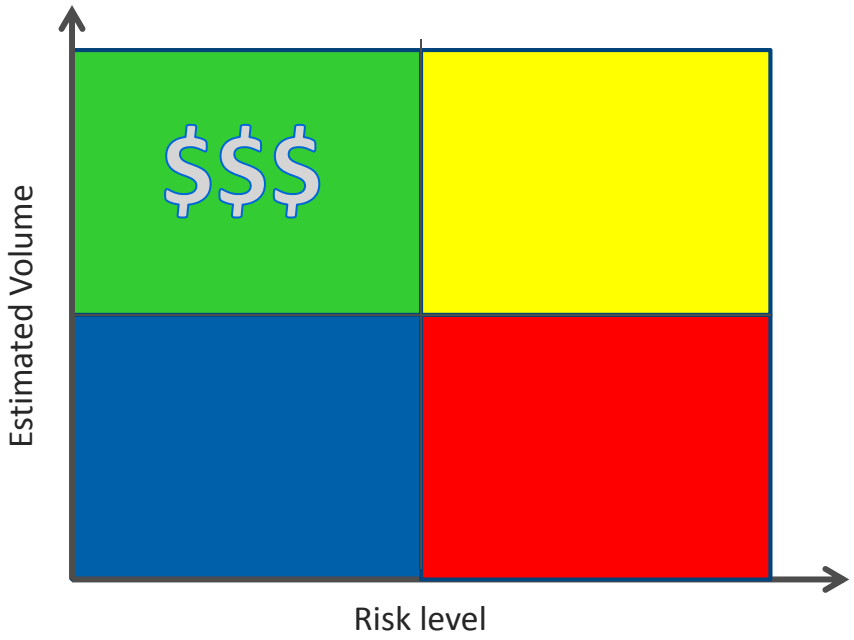
From P. Delfiner

Risks and uncertainties

- **Risk**
  - Risk is the probability that the parameter of interest fails to work at the minimum expected level
  - Example: will this well find oil? ➔ probability (POS)
  - Modeled through a probability
  - Decision trees allow to combine scenarios with various probability of success
- **Uncertainty**
  - Uncertainty is about the variation of a given parameter in the range of possible outcomes
  - Used to make development decisions
  - Example: how much oil will this well produce? ➔range of values
  - Modeled through a probability distribution function
  - Monte-Carlo simulations allow to get realization by following a given probability distribution function

Stakes at risk

- POS expresses the subjective, qualitative assessment
- Uncertainty expresses the objective, quantitative assessment
- POS and uncertainty are correlated
- Stakes => combination of POS and estimated uncertain volumes => make decision



Example of risk and uncertainty - 1



Suppose the payoff of a project is determined by spinning a roulette as shown in the picture (in $ million).

Would you recommend this project?

Uncertainty	the revenue may be $-10, $10, or $30	
Risk	50% chance of losing	$-10
	25% chance of earning	$+10
	25% chance of earning	$+30

Example of risk and uncertainty - 2



We cannot predict what the outcome will be.

We cannot eliminate the risk but we can understand it and quantify it.

For example we can calculate what we will get in average, i.e. if we spin the wheel many times, or if we have a portfolio of similar projects.

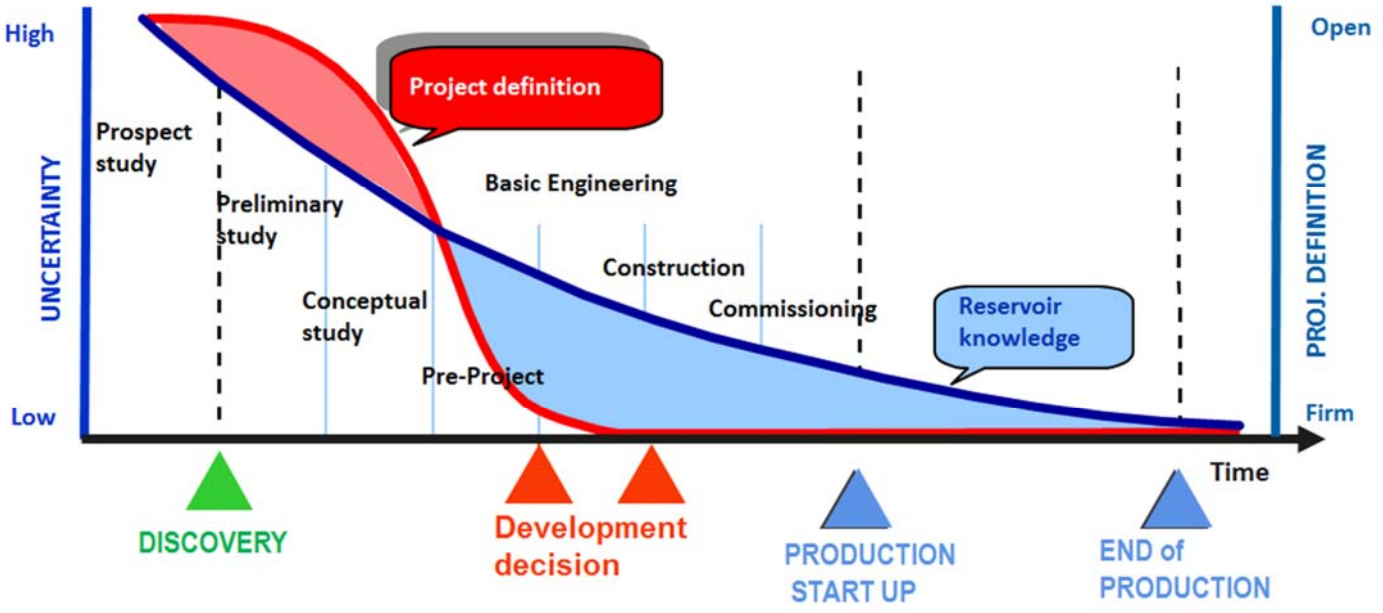
Expected payoff = 1/2 x ($-10) + 1/4 x ($10) + 1/4 x ($30) = $5

Probability-weighted average of all possible outcomes

The project may be recommended

Uncertainty in the field life cycle: the theory

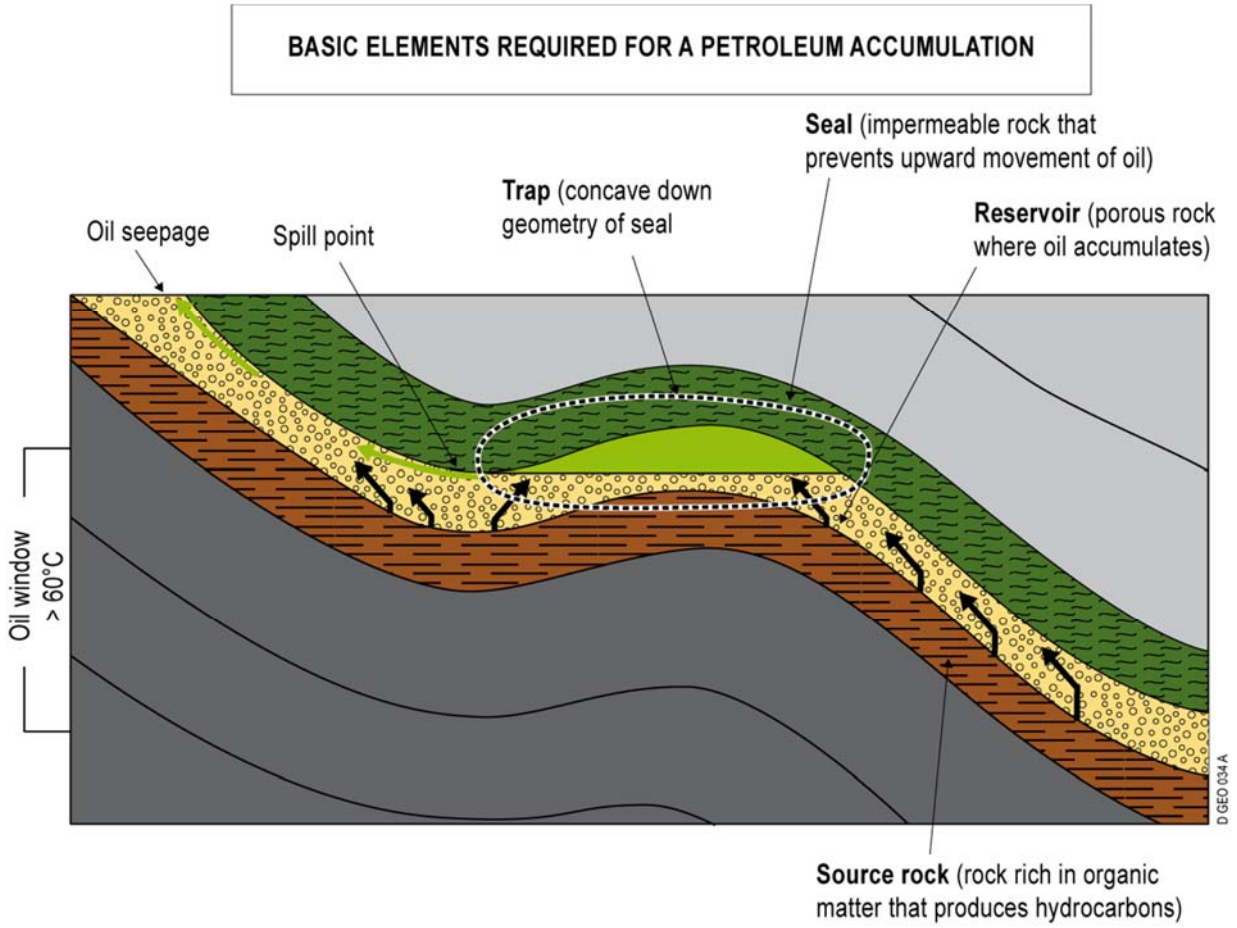
- Reservoir knowledge and project definition increase monotonously with time, though not at the same rhythm



Risks assessment

- **The risk stands for any geological reason that might rule out the geological hypothesis or model:**
  - Should a risk happen to come true, it would invalidate the prospect assessment.
  - Evaluating the risk on a prospect means measuring the prospect failure probability.
- **Given a geological hypothesis or model:**
  - The uncertainty measures the lack of capacity to ascertain the actual value of a parameter.
  - The uncertainty does not invalidate the hypothesis or the model.
- **Risk assessment can also be linked to projects such as:**
  - Value of information by shooting 4D seismic to evaluate by-passed oil
  - Value of information by shooting new seismic to improve the reservoir characterization, thus improving the development plan in (water or gas) injection projects.
  - ……..

The elements that make a petroleum accumulation



Geological risk assessment

- **The geological risk assessment requires an evaluation of those geological factors that are critical to the discovery of recoverable quantities of hydrocarbons**
- **The probability of discovery is a function of the major probability factors, each of which must be evaluated with respect to presence and effectiveness**
- **As they are considered independent, the POS is the multiplication of all the single risk values. Depending on companies, the POS can be the multiplication of 3 to 8 single risks.**
- **Probability Pj of:**
  - Reservoir
  - Trap
  - Hydrocarbon charge
  - Timing of migration
  - Retention of hydrocarbons in the trap
  - ….

$$POS = \prod_{j=1}^{n} P_j$$

Expected value of a discrete variable

- **The expected value E(X) of a discrete random variable X is the probability-weighted average of all possible outcome values.**

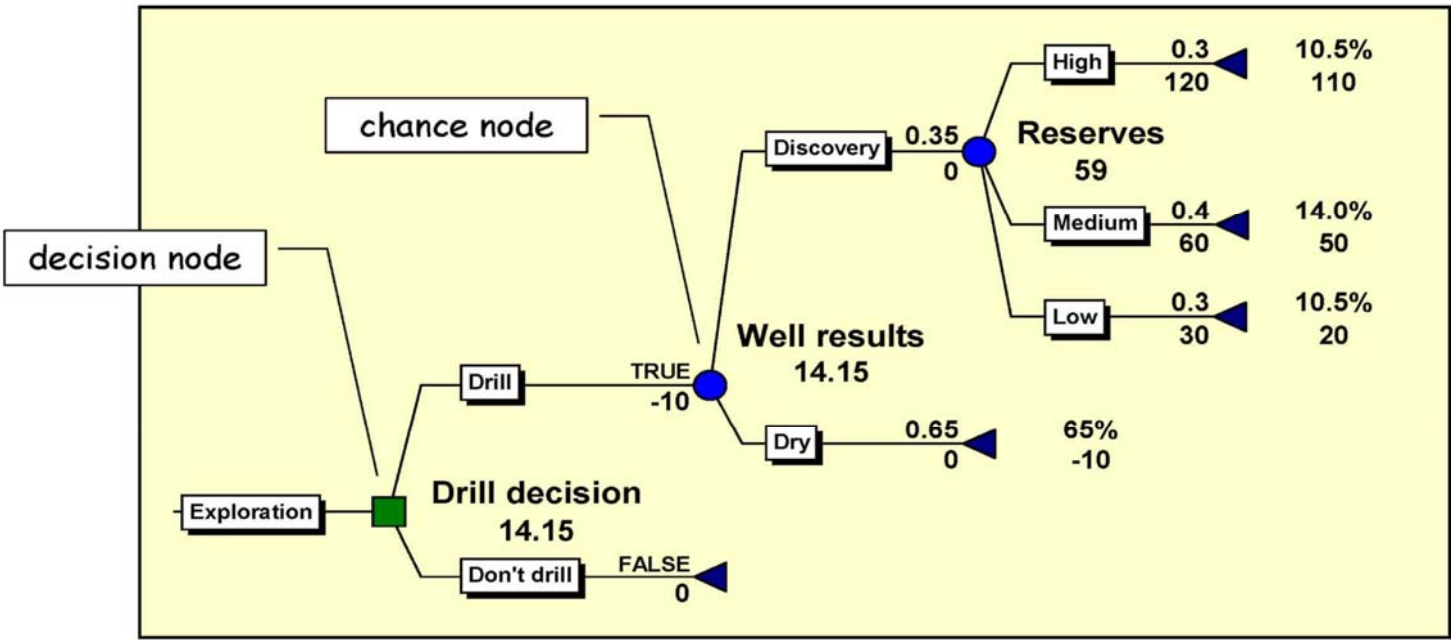
Value of X	x_1	x_2	x_3	▪▪▪	x_n
Probability	p_1	p_2	p_3	▪▪▪	p_n

$$E(X) = p_1 x_1 + p_2 x_2 + p_3 x_3 + \ldots + p_n x_n$$

- **Similarly, we can define the expected monetary value EMV:**
  - **It is the probability weighted average of all the possible $(NPV)_i$**

Decision tree

- A graphical tool to model decisions and chance outcomes



Notes

Assessment of reservoir uncertainties

- Overview of uncertainties

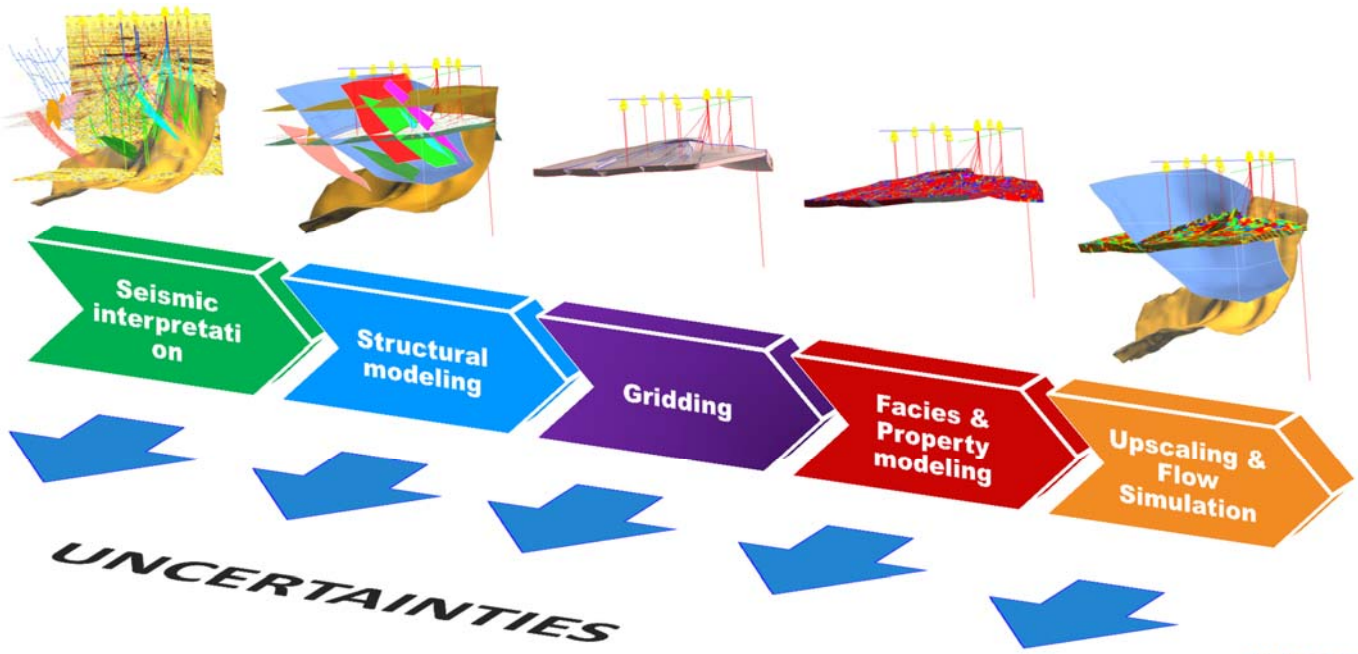


Overview of uncertainties : outline

A. **Key steps of a field development project**
B. Uncertainties must be managed at each step.
C. A brief overview of what geophysical uncertainties are
D. A brief overview of what geological uncertainties are
E. A brief overview of what reservoir uncertainties are
F. Conclusions

Key studies of a field development project

- From seismic interpretation to flow simulation
- Complex and integrated process
- Each step includes specific uncertainties that must be identified and shared with other steps.



Overview of uncertainties : outline

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When are you concerned by uncertainties?

Traditional schedule (mono scenario)



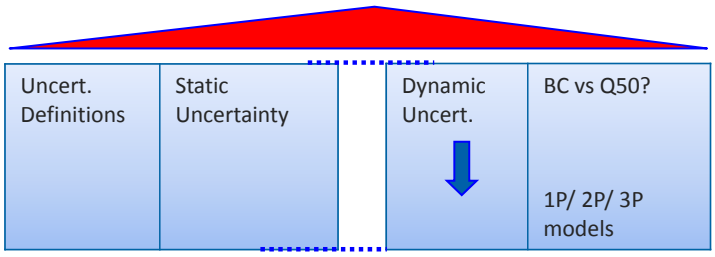


Gap

Final Goal…

Final simulation 1P/ 2P/ 3P	1P SEC model

If works are not anticipated before
You will have TROUBLES !



Uncertainty study = long process !

RISKS WHEN WORKING LIKE THAT:

- Gap/ delay in term of project schedule
- 1P/ 3P/ 1PSEC derived after base case building (inconsistency, delays)
- Base case could be off after uncertainty study! Difficult to change!
- A priori Choice/ Validation of base case could bias the uncertainty study



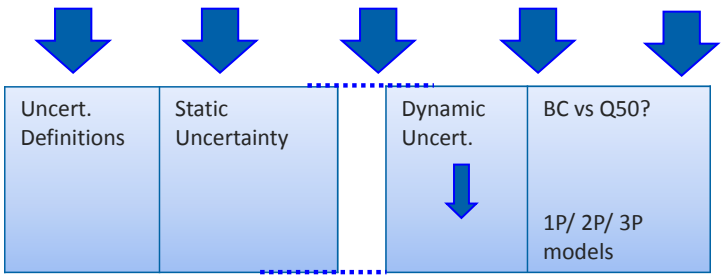
STOP WORKING LIKE THAT !

When are you concerned by uncertainties?

Proposed schedule (multi scenario)

Team including uncertainties in daily work…





Final Goal…

Final simulation 1P/ 2P/ 3P	1P SEC model

Uncertainty study = simultaneous process!

BENEFITS WHEN WORKING LIKE THAT:

- Uncertainties are provided by each discipline during workflow
- 1P/ 2P/ 3P perimeters are defined in advance for the sake of consistency (static & dynamic)
  - Compatibility between reality and rules (Company rules, SEC)
- Base case is defined and validated in the same time than the 1P and 3P
  - BC is part of the same distribution
- Prelim. base case could be revised to fit Q50 when justified.



Overview of uncertainties : outline

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F. Conclusions

Uncertainties in structural interpretation

The whole challenge in one formula !

Reserves = GRV * NTG * PHIE * Shc * FVF * RF

Gross rock volume
(Hc bearing GRV)
3D Volume of interest
Limited by key surfaces
Coming from interpretation

STRUCTURAL UNCERTAINTIES

Net to gross : ratio of reservoir volume
PHIE : connected/effective porosity
SHc : Hydrocarbon sat.

Obtained by well information
Sedimento context
Seismic attributes interpretation

RESERVOIR STATIC UNCERTAINTIES

FVF: volumetric factor (1/Bo)
RF : Recovery factor

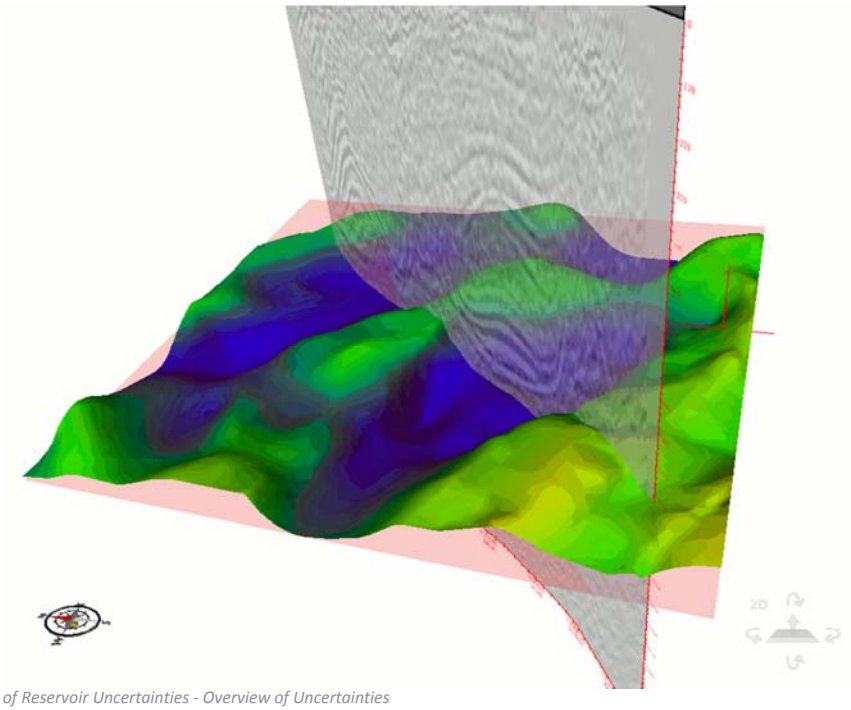
RESERVOIR DYNAMIC UNCERTAINTIES

A brief overview of what geophysical uncertainties are

- Seismic interpreter extracts key surfaces (horizons, faults, …) from

  seismic data = unperfect blurred distorted 3D image of underground.

- So, seismic interpretation base case is only one possible realization !

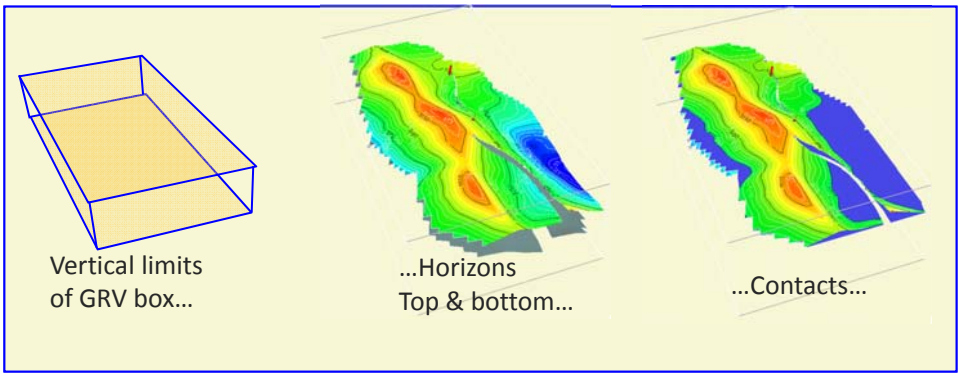


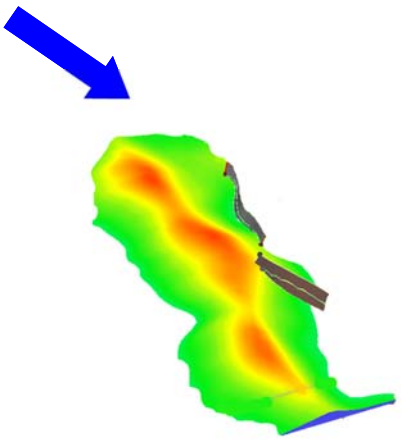
Example of a 4-way dip closure field:
- Due to picking uncertainties
- Due to time-depth conversion uncertainties

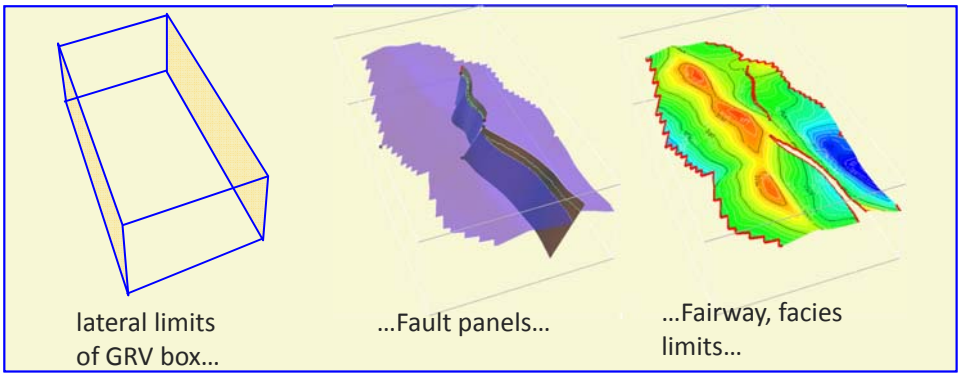
=> Geometry of the field is changing!

Uncertainties in structural interpretation

Definition of the GRV box







Final
GRV box
(Hc bearing only)

Uncertainty assessment workflow

Methodology for structural uncertainties

ANALYSIS of DATA & INTERPRETATION METHODS

- **Identify** uncertainties in interpretation workflow,

INTERPRETATIVE STATISTICAL GEOSTATISTICAL TECHNIQUES

- **Quantify** their magnitude,
  - Rank them in terms of impact on the results & keep the most influential,
  - Define scenario, confidence interval

DEDICATED TOOLS

- **Process** the uncertainties
  - Simulation
  - GRV calculation

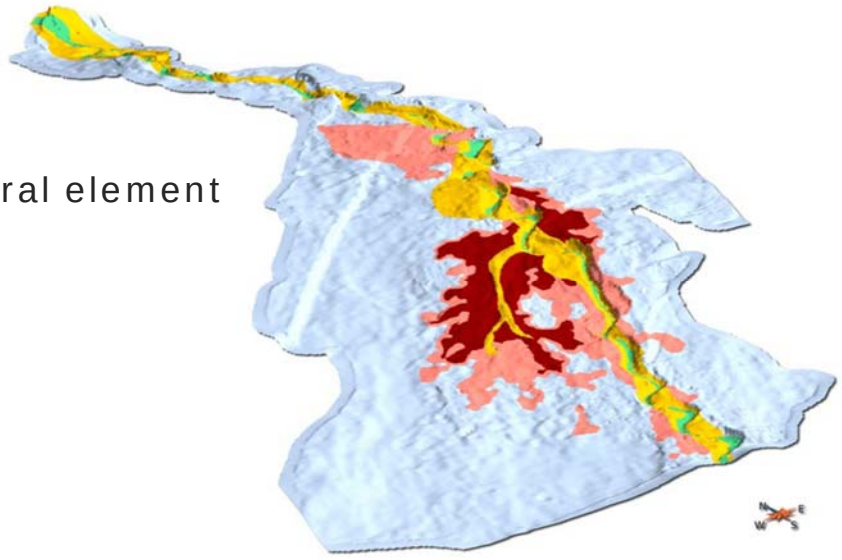
Overview of uncertainties : outline

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D. **A brief overview of what geological uncertainties are**
E. A brief overview of what reservoir uncertainties are
F. Main approaches (deterministic, scalar/spatial Monte-Carlo)

A brief overview of what are geological uncertainties

- **Geological interpretation includes 3D description of:**
  - Architectural elements and facies settings
  - Petrophysical properties (NTG, PHIE, Shc, …)
- **It is possible to associate uncertainties to these key parameters that will modify the final volumes and reserves.**

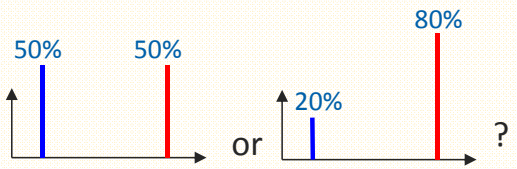
Uncertainty on architectural element limits
Camelia - Cx13A



Geological uncertainties: various types

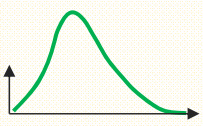
Uncertainties can be classified as





"meta-scenario": different hypotheses that cannot be considered as the realizations (or occurrences) of a single statistical process, probability is difficult to define = discrete possibilities (no intermediate states)





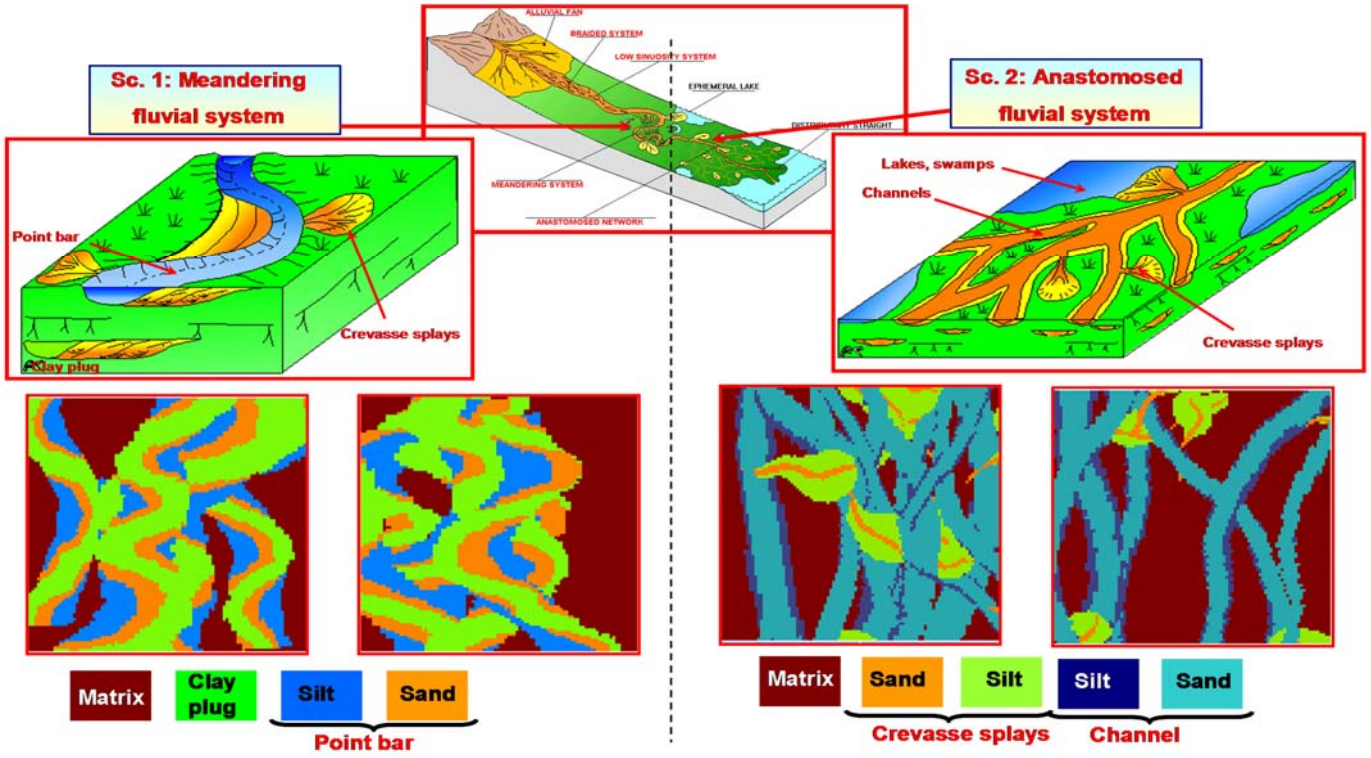
"pseudo-scenario": different hypotheses that can be considered as the realizations (or occurrences) of a single statistical process, probability can be retrieved from the **distribution law** = continuous possibilities

3 types of uncertainty for "pseudo-scenario "

- **on data**
- **on mean**
- **on residual**

Scenarios: examples of “meta-scenarios”

- Different geological schemes or mechanisms of deposition



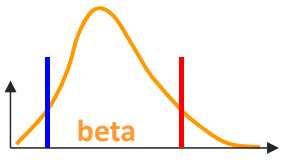
From P. Henriquel and al.

Scenarios: examples of “pseudo-scenarios”

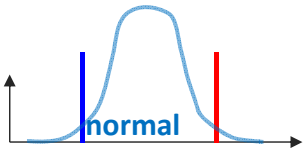
- Hypotheses for fluid contacts



- Hypotheses for proportions of facies



- Hypotheses for average petrophysical values



Petrophysical uncertainties

Example on the data set



- **Example of data uncertainty issued from log analysis:**
  - Saturation log Sw derived with Archie's law

$$S_w^n = \frac{a}{\phi^m} \cdot \frac{R_w}{R_t}$$

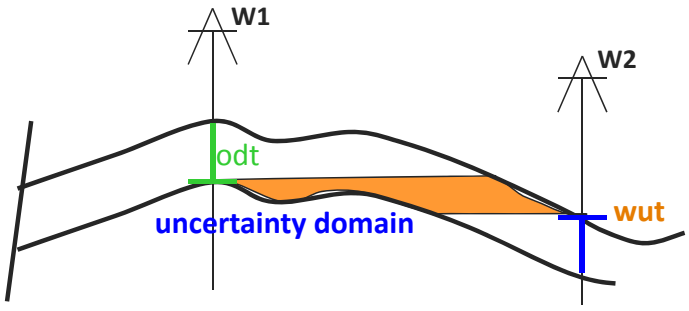
Rw = water resistivity
Rt = global resistivity log
a, m, n Archie's parameters

optimistic
most likely
pessimistic
} different parameter sets

- **Systematic bias may rise from interpretation**
  → **Consequence on average values mainly**
- **Measurement errors (not systematic)**
  → **Consequence on residual values mainly**

Fluid filling: contacts uncertainties

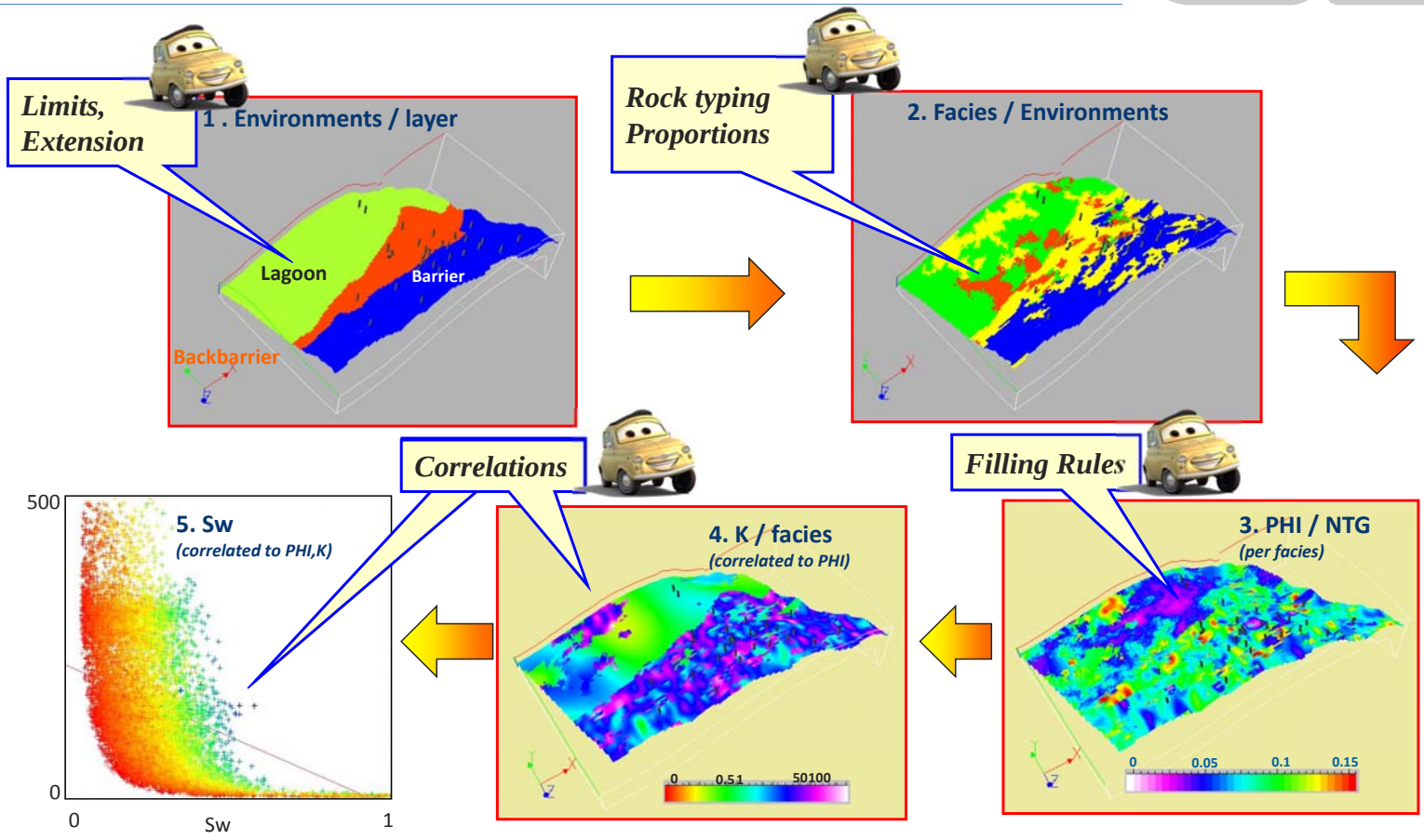
- **The fluid contact has not been observed at wells:**
  - Define the bounds of the uncertainty domain:
    - For water oil contact (WOC): water up to (WUT), oil down to (ODT)
    - For gas oil contact (GOC): oil up to (OUT), gas down to (GDT)
    - For gas water contact (GWC): water up to (WUT), gas down to (GDT)



define the most probable values (mode of distributions):

- **use the direct hydrocarbon indicator (DHI) on seismic and uncertainties**
- **use fluid sample composition**

Geological uncertainties global workflow



Geological uncertainties

Geological modeling scheme

NESTED SIMULATIONS

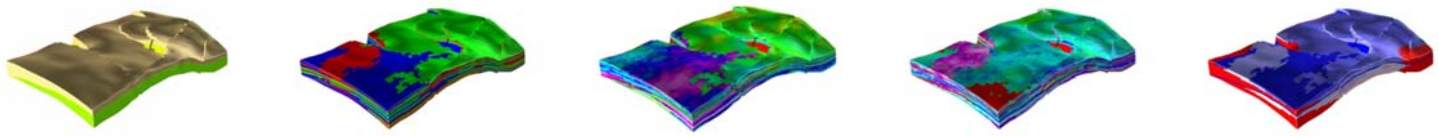
Geometry: Surfaces, thickness

Sedimentary: Multi-level embedded facies modeling

Petrophysics: Porosity, N/G, K_x, K_y, K_z and any user-defined variable…

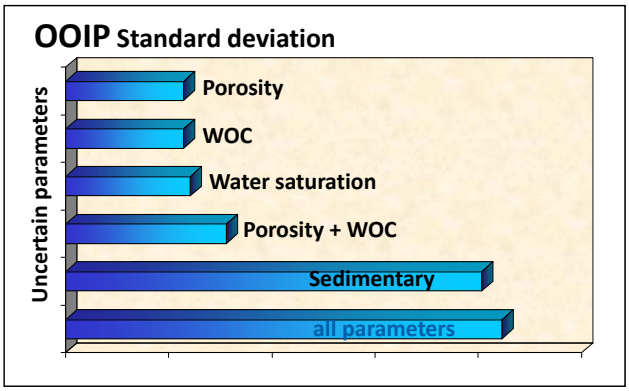
Contacts: OWC, GOC

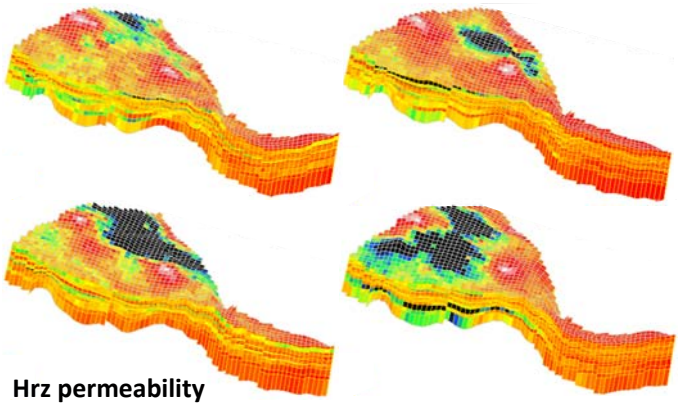
Fluids: Water saturation, Bo…



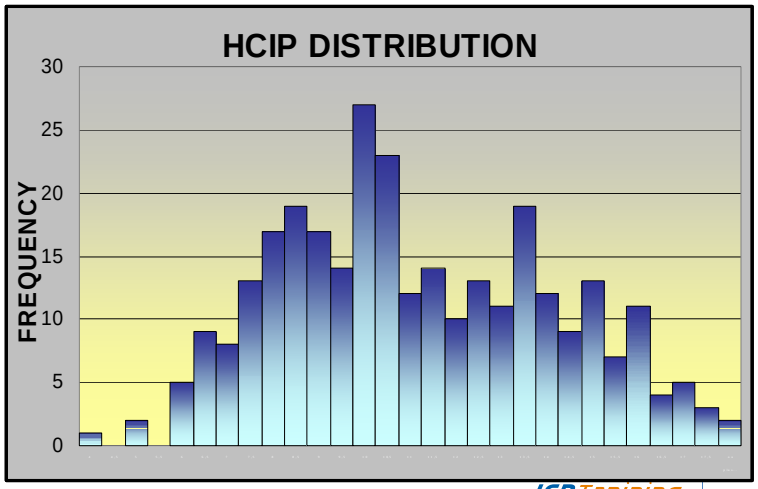
Reserves probabilistic distribution - G&G

- **Results of geological and structural uncertainties**
  - Distribution of hydrocarbons in place
  - Ranking of uncertainties
  - Reservoir models





Hrz permeability



Overview of uncertainties : outline

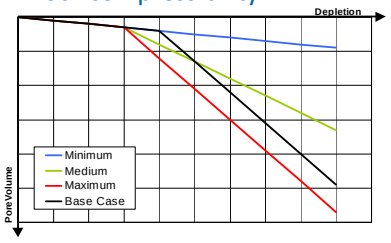
A. Key steps of a field development project
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Dynamic uncertainties

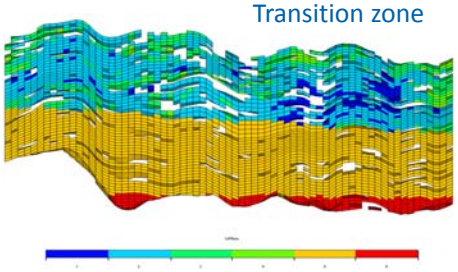
Usually a lot of dynamic uncertain parameters corresponding to flow simulator parameters:

- Level of absolute permeability
- Relative permeability curves (shapes and end points)
- Fault transmissivity
- Barriers to vertical flow transmissivity
- Aquifers (sizes, strength, permeability…)
- PVT (viscosity, compressibility)
- Rock compressibility
- Wells (skin, Injectivity Indexes)
- Operating conditions
  - Wefac, flowline, GL, horizontal drain …
  - Water injection availability
  - Drilling schedule …

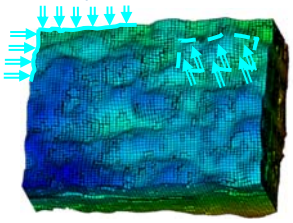
Rock compressibility



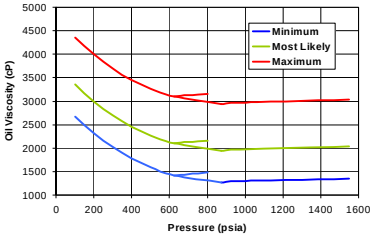
Transition zone



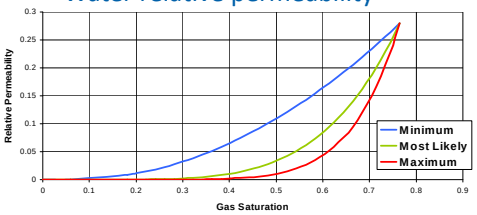
Aquifers



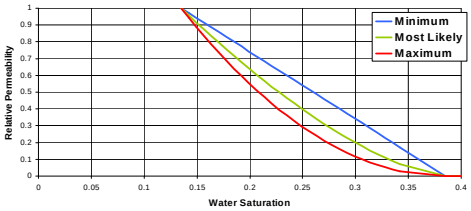
Oil viscosity



Water relative permeability



Oil relative permeability



How can we explore such a domain of uncertainty ?

Dynamic uncertainties

HOW CAN WE EXPLORE SUCH A DOMAIN OF UNCERTAINTIES ?

The problem:

- QUANTIFYING DYNAMIC UNCERTAINTIES REQUIRES RUNNING SEVERAL DYNAMIC SIMULATIONS INVOLVING LARGE SIMULATION RUNNING TIME (TCPU)

- Not realistic!

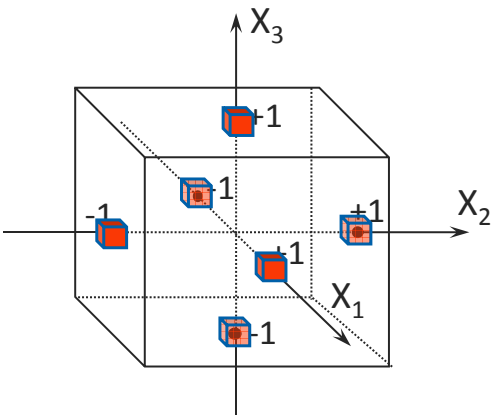
The solution:

- NEED TO SELECT PERTINENT DEVELOPMENTS ONLY:

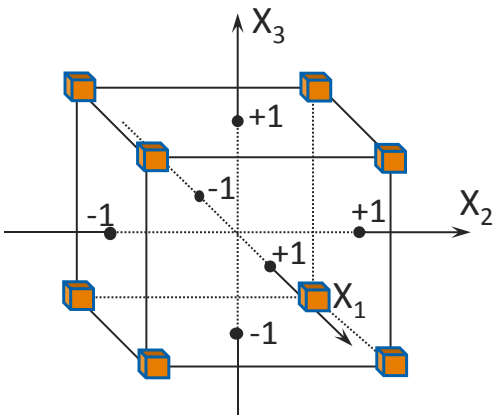
USE EXPERIMENTAL DESIGN METHODOLOGY

Generalities

Classical sensitivity



Experimental design

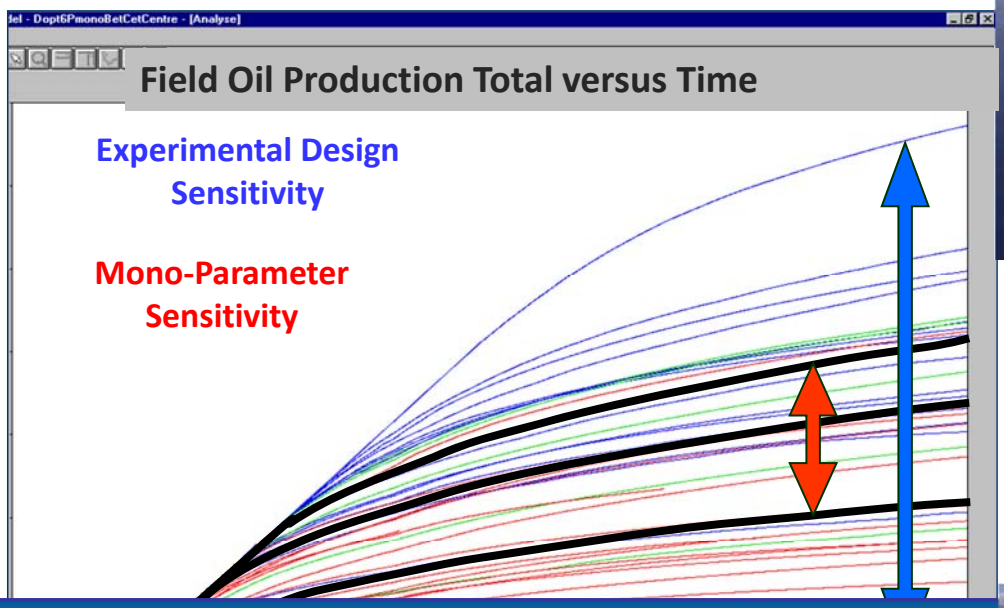


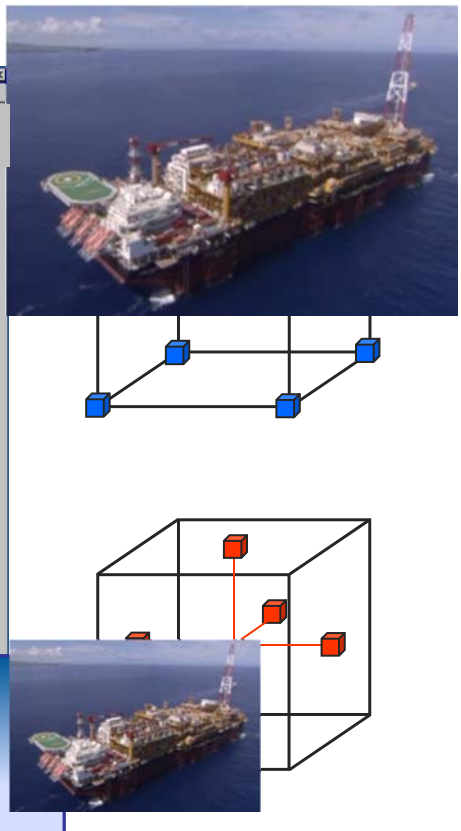
X_3= Oil viscosity

X_2= Aquifer strength

X_1= Fault transmissibility

Experimental designs: generalities

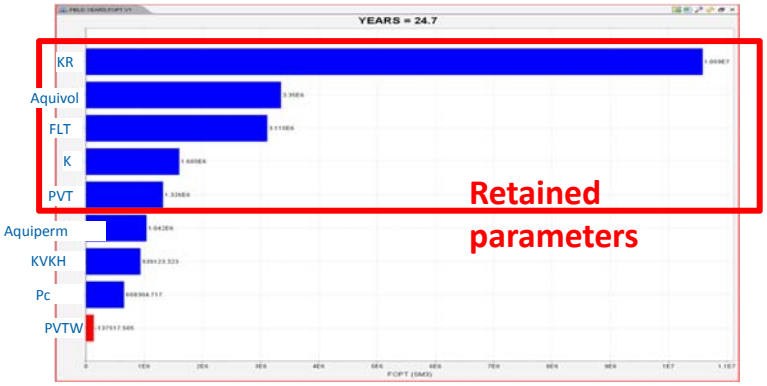


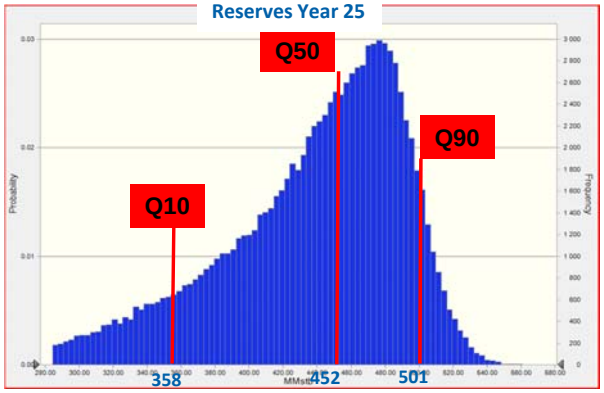


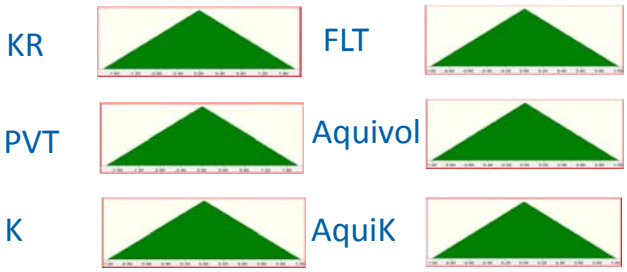
Ignoring simultaneous effects and interactions of multiple uncertain parameters may lead to a drastic underestimation of uncertainties.

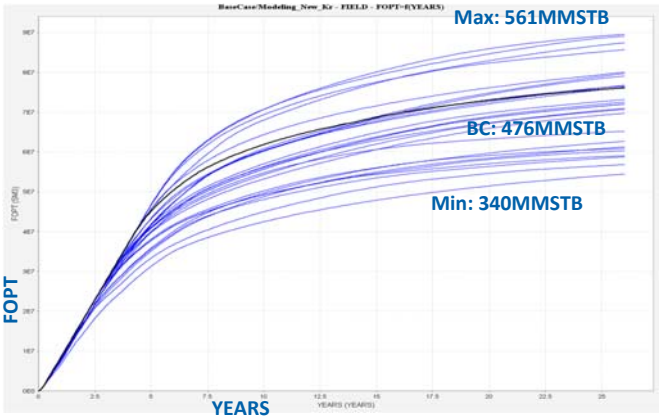
Reserves probabilistic distribution

- **Results of dynamic uncertainties study**
  - Ranking of uncertainties
  - Distribution of reserves
  - Production profile









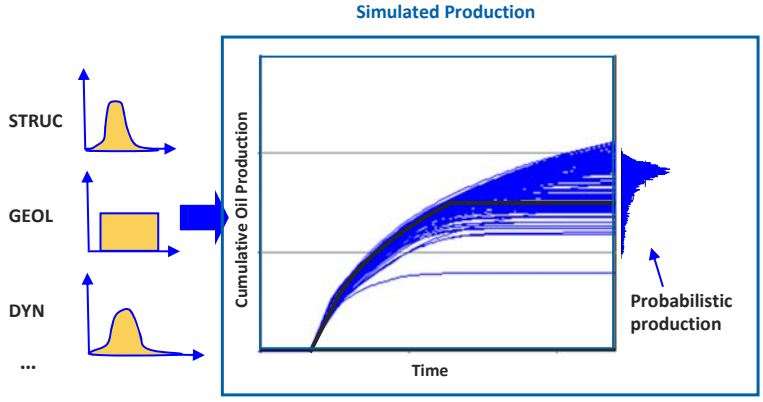
A brief overview of what are reservoir uncertainties

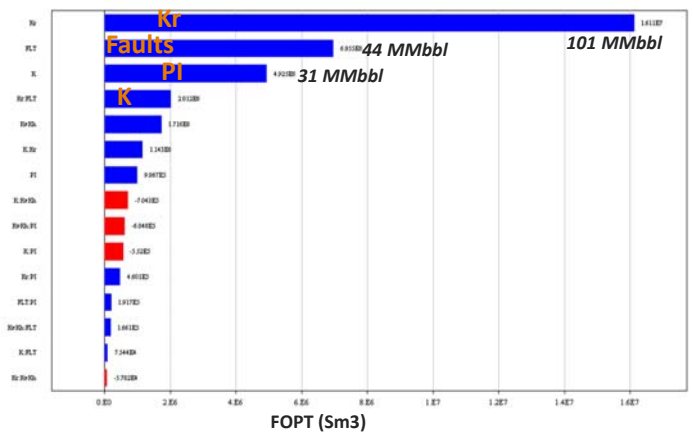
Reservoir studies predict production results from estimated dynamic parameters. Depending on the chosen values of these dynamic parameters, final reserves are different.

Permeabilities and other reservoir dynamic properties (fluid properties, aquifer parameters,…) are uncertain: dynamic uncertainty studies allows to quantify the impact on the final reserves / production profiles, …

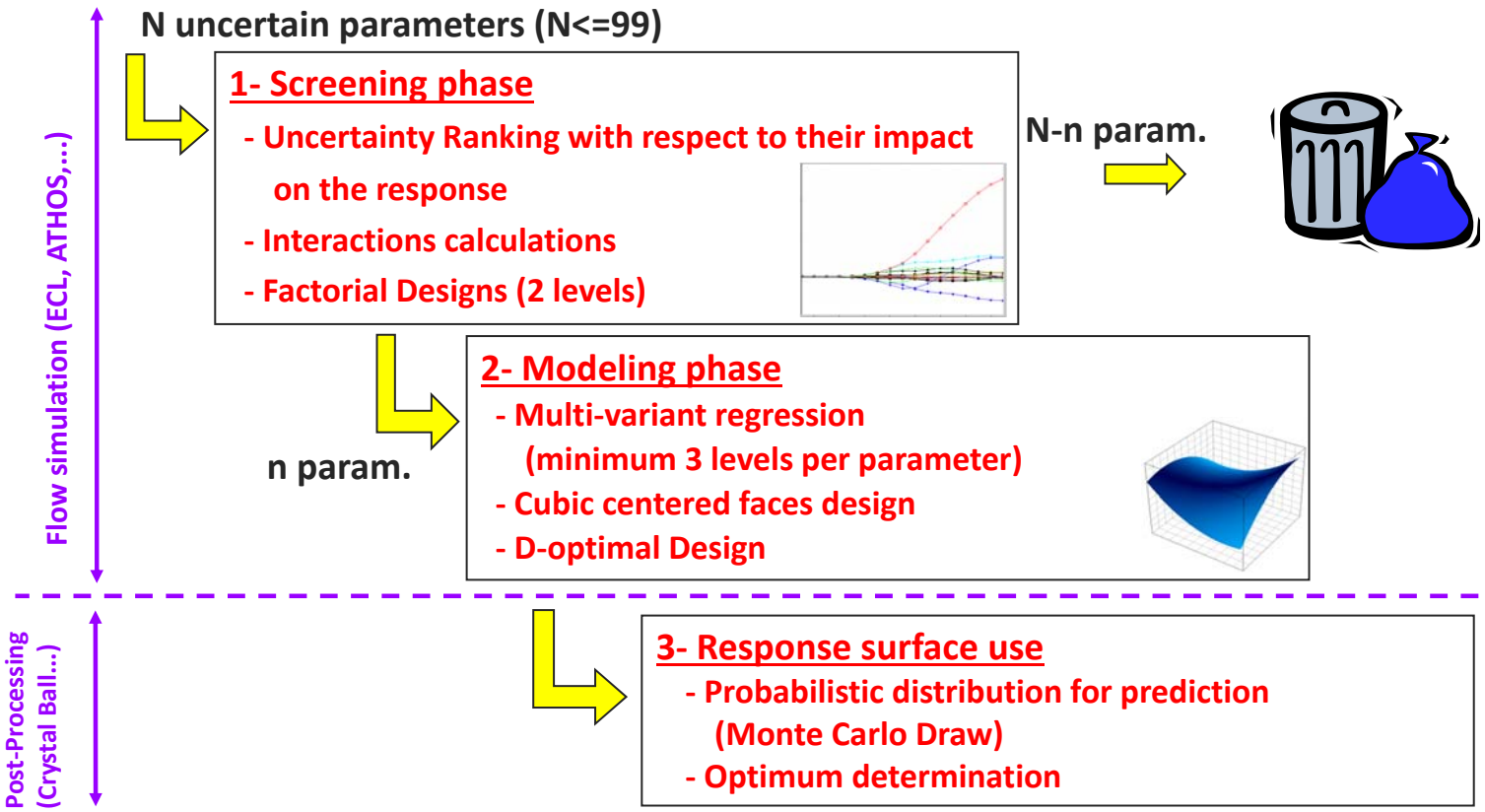
Effects of static uncertainties (geophysical and geological) shall also be taken into account.

Example : production profiles and tornado chart indicating impacts of input parameters on final reserves





Classical workflow



Dynamic uncertainties

- **Workflow**
  - List, quantify static uncertainties
  - Generate several geomodels and OOIP distribution
  - List, quantify dynamic uncertainties
  - Built a correlation plot Accu/Reserves using average value for dynamic parameters
  - Select 3 or 5 static geomodels (~Q10,~Q50,~Q90)
  - Built on each geomodel the reserve distribution related on dynamic uncertainties by using the experimental design method.
  - Mixed static and dynamic uncertainties using anamorphosis method to generate global reserve distribution.

Uncertainty workflow

- **Can assess & manage uncertainties in a double approach:**
  - Downstream: Which impact do the identified uncertainties have on the results?
  - Upstream: Which uncertainties increase a risk and which level of risk is acceptable without reducing uncertainties ?

Dynamic uncertainties

Uncertainty approach: another way to work

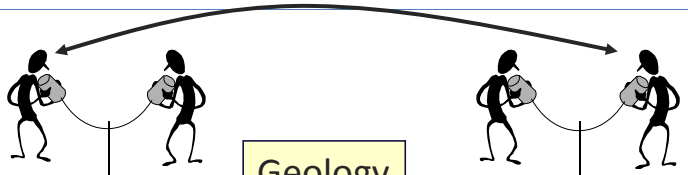
- **All actors of a project involved to identify uncertainties within each technique than can have impact on intermediate and final results.**
- **Planned approach of the problems**
- **Awareness of the necessity to:**
  - share data
  - exhibit doubts, weaknesses
  - keep all possibilities, etc..

⇨ **Risk assessment less subjective**

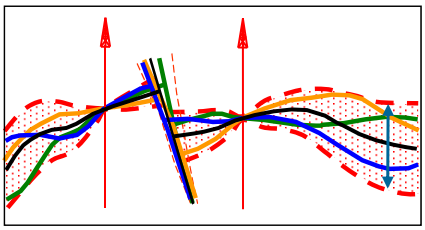
Overview of uncertainties : outline

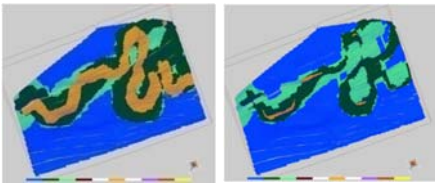
A. Key steps of a field development project
B. Uncertainties must be managed at each step.
C. A brief overview of what geophysical uncertainties are
D. A brief overview of what geological uncertainties are
E. A brief overview of what reservoir uncertainties are
F. **Main approaches (deterministic, scalar/spatial Monte-Carlo)**

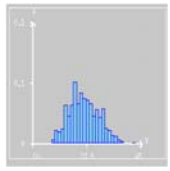
The reservoir model: uncertainties

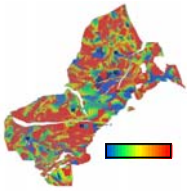


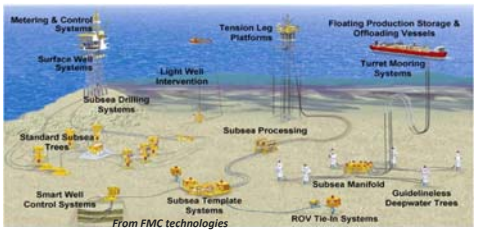
Geophysics | Geology | Reservoir

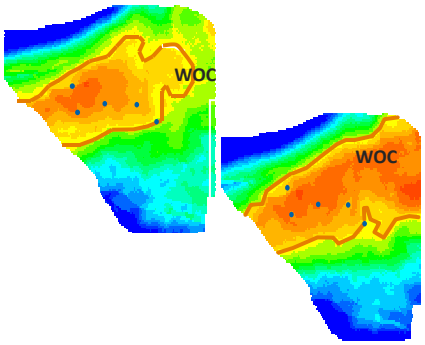


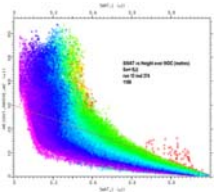


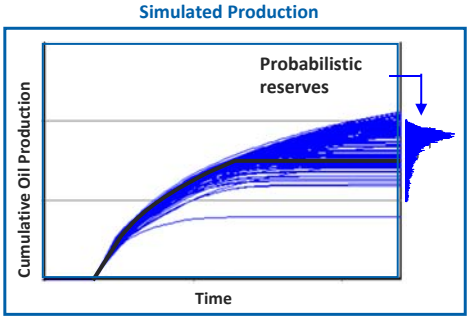












Geometry - envelop

Sedimentary – Fluid Petrophysics

Flow parameters, Drive mechanism

Uncertainty assessment techniques

Direct MC | Scenarii | Spatial MC

Direct Monte Carlo

Input data → Uncertainties → Monte carlo → *Static volumes* → Uncertainties

- *3D effects not taken into account*
- *More difficult than expected in general*
- *No 3D models for modelling*

Scalar Monte Carlo method

$$\text{Re}\,serve = GRV \times \Phi \times NTG \times S_o \times RF$$

- **Analytical approach**
- **Reservoir considered as a cube**
  - Various uncertain variables
    - Gross Rock Volume (GRV)
    - Net To Gross (NTG)
    - Porosity (Φ)
    - Oil saturation (S_o)
    - Recovery Factor (RF)
  - Variation range for each parameter
  - Correlation between parameters
  - Random Monte Carlo draw (e.g. using Crystal Ball)



+ Advantages

- Fast approach
- First idea about Reserves Distribution

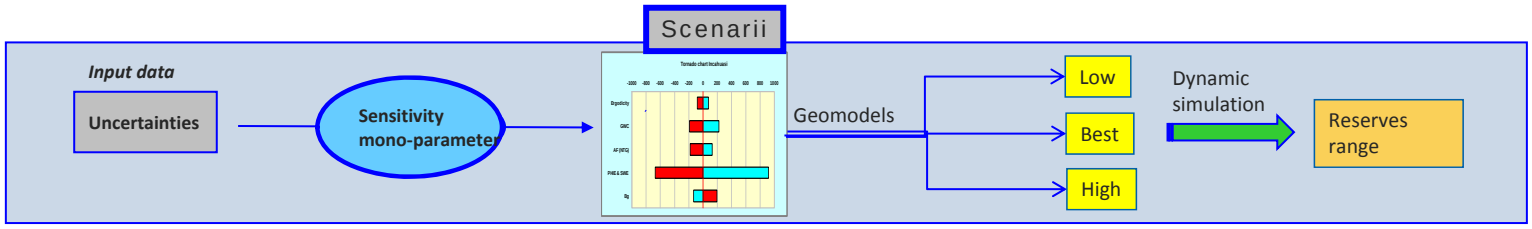
Quick look, sometimes OK!

- Drawbacks

- No geology introduced in the computation
- No spatial repartition (only a global figure)
- Difficulties to compute uncertainties on parameters
  - Without tools for GRV
  - Recovery factors?
- Very partial exploration of the uncertainties

Uncertainty assessment techniques

Direct MC | Scenarii | Spatial MC



- **Single best estimate** "Base case"
  - **Input parameters**
    - Most likely structural interpretation
    - Most likely geological point of view => 2P reserves
    - Most likely engineering parameters
  - **Sensitivities on uncertain parameters**
    - Most influent parameters set as unfavorable => 1P reserves
    - Most influent parameters set as optimistic => 3P reserves



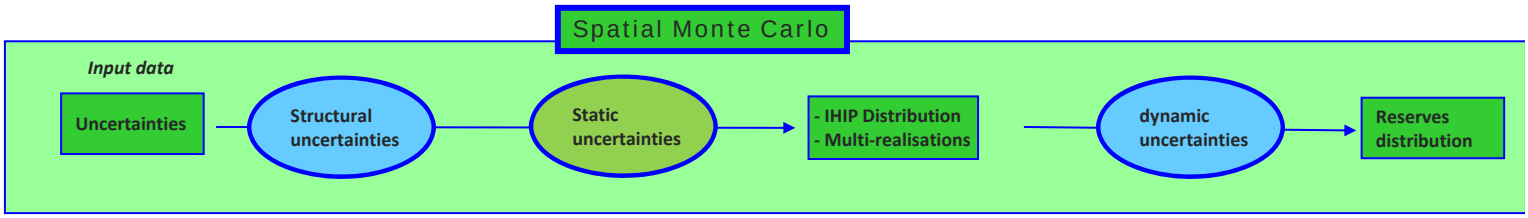
+ Advantages
- Well known workflow
- All input parameters well identified
- Simple to apply
- Easy to comply with SEC rules (contacts …)

- Drawbacks
- Subject to human judgement:
  - Most Likely?
- No propagation of uncertainties (only sensitivities)
- Incomplete risk evaluation
- "Base Case" not Median but Most Likely
- "1P" / "3P" not statistically proved

Avoid working like that!

Uncertainty assessment techniques

Direct MC | Scenarii | Spatial MC



- **Reservoir (geometry and filling) is described**
  - Maps of parameters
  - Using geostatistics (for spatial distribution=
  - Same constraints as "Base case" model
    - Blocked well data
    - Petrophysical distribution
    - Variogram …
  - Uncertainty on scalar variables also introduced
    - Contacts, PVT, …

All models may be transferred into dynamic simulations

You may accelerate the process by anticipating this phase !



Long but Accurate !

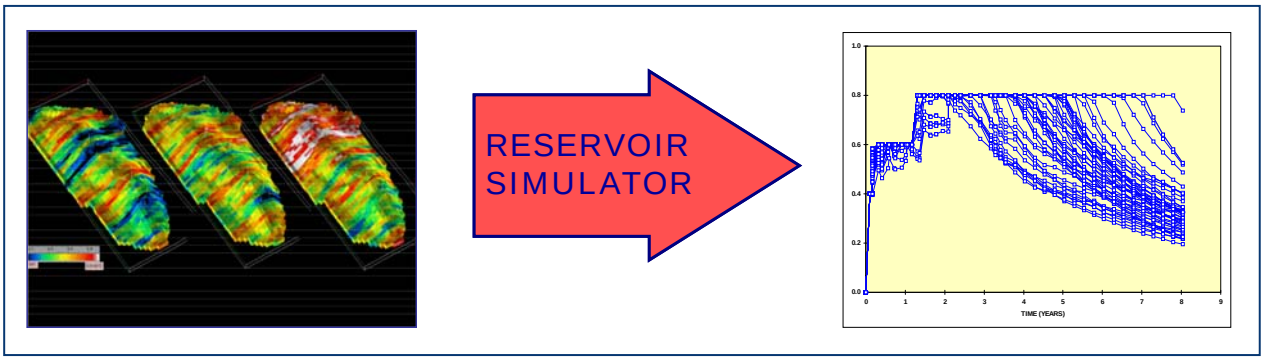
+ Advantages
- Formal quantification of uncertainties
- Complete exploration of the uncertainties
- Less human judgement
- Allows 3D localization of the uncertainty
- Coherent transfer to dynamic

- Drawbacks
- Preparatory phase is needed to evaluate all input uncertainties
- Addition effort is needed to integrate uncertainties in the existing model workflow
- Might be long and therefore expensive

Spatial multi-realization approach

Several hundreds of developments of the geomodel are statistically built and dynamically simulated.

From this approach, we expect to cover realistically uncertainties for any property at any spatial location in the reservoir.



Two ways of exploration of possible inputs:

- **Systematic** exploration (Spatial Monte Carlo)
- **Planned** exploration (Experimental design technique)

- Any field development project needs a **probabilized result** (1P, 2P, 3P models)
- Uncertainties must be **evaluated at all steps** of the seismic interpretation / geomodeling / reservoir simulation workflow.
- This work must be **done simultaneously** with the construction of the b ase case.
- This work must be **integrated** between the 3 disciplines (geophy., geol., res.).
- **Several approaches** are possible (deterministic, scalar, spatial Monte-Carlo,…).
- These approaches give different results and have different limits.